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ADVANCING CONSTRUCTION PRACTICES: INNOVATIONS, EFFICIENCY, AND SAFETY IN THE DIGITAL ERA

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In the ever-changing landscape of the construction industry, digital tools and procedures are a cornerstone of architectural and engineering practices. Building Information Modeling (BIM) and other computational design methodologies transform how projects are imagined, planned, and executed. These tools improve design precision while allowing real-time collaboration across different teams. As a result, adopting digital approaches is no longer an option but rather a requirement for remaining competitive in the construction industry. These innovative approaches provide an in-depth understanding of project complexities, drive design optimization, and contribute to resource management efficiency.

Construction efficiency has also improved due to lean manufacturing processes and process optimization techniques. These approaches emphasize waste reduction, improved workflows, and increased productivity, which are critical to meeting project timelines and budgets. In this age of technology, combining lean methods with advanced software tools empowers project teams by allowing them to accomplish more with less effort and cultivating a culture of continuous improvement. By combining traditional lean strategies with current digital tools, the construction industry is setting new benchmarks for operational efficiency.

Safety and stakeholder involvement are other important factors that benefit greatly from technology improvements in the construction industry. Enhanced safety measures, backed by digital technology, ensure that safety practices are strictly followed and monitored. Furthermore, digital platforms boost stakeholder engagement by giving all parties—from project managers and workers to investors and clients—access to real-time data and analytics. This transparency not only builds confidence but also guarantees that everyone engaged is aware of safety requirements and the progress of the project. This collaborative environment is critical for detecting potential risks early on and encouraging a proactive attitude to workplace safety.

In addition to technological and methodological developments, the construction industry is becoming more focused on resilience and sustainability. Climate change and environmental sustainability require construction approaches that not only reduce environmental effects but also assure infrastructure resilience when unforeseen events occur. Sustainable practices are being integrated into project lifecycles to reduce carbon footprints, increase energy efficiency, and use environmentally friendly materials. Digital tools are critical in this effort, from optimizing resource consumption to allowing for the simulation of environmental implications during the design stage.

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The convergence of digital tool innovations, lean process efficiency, improved safety regulations, and sustainability-oriented practices represents the construction industry's future. This comprehensive strategy meets the immediate needs of project efficiency and safety and corresponds with larger environmental and societal objectives. As we manage the challenges of modern construction, adopting these integrated techniques will be critical for creating smarter, safer, and more sustainable infrastructures for the digital age.

Promoting Research on Innovations, Efficiency, and Safety

In this edition of the CSID Journal of Infrastructure Development, we present insightful papers exploring various aspects of construction practices, reflecting the ongoing advancements and challenges in this field.

The first paper, written by Fitriansyah and Latief, develops a jetty structure design procedure using Computational Design (CD) and BIM to improve time performance at the schematic design stage. The study highlights nine critical business processes and 37 design activities that enhance design time performance. These findings demonstrate the significant benefits of integrating CD and BIM in civil engineering projects.

The second paper, written by Ajiboye et al., analyzes local and global construction material sourcing strategies for road projects in Nigeria. The study reveals that local sourcing offers advantages in delivery and cost savings, while global sourcing provides advanced materials. The research concludes that improving local material quality through advanced manufacturing technologies could benefit the Nigerian economy greatly.

The third paper, written by Dewi et al., identifies influential factors in the risk cost estimation process of implementing BIM 5D in Quantity Take-Off (QTO) for green retrofitting high-rise buildings. The research highlights the importance of accurate cost estimation to improve project management and sustainability. This study demonstrates how BIM 5D QTO can mitigate risks and enhance cost accuracy in green retrofitting projects.

The fourth paper, written by Saputra et al., examines the accuracy of contour data obtained through photogrammetric and terrestrial surveys. The study compares Digital Terrain Models (DTM) generated using Unmanned Aerial Vehicles (UAVs) with traditional Total Station measurements, finding higher accuracy in the latter. The findings underscore the importance of selecting appropriate survey methods based on required precision and project needs.

The fifth paper, written by Dwianditya et al., investigates critical success factors for the performance of lean manufacturing project in pump production for flood management infrastructure. The study emphasizes project complexity management, design alignment, and technical process mastery. By identifying these key elements, the research provides valuable insights for improving production efficiency in flood mitigation projects.

The sixth paper, written by Tahir and Idris, identifies critical factors influencing the build-back-better framework and resilience building in post-flood recovery efforts. The study utilizes Multi-Criteria Decision Making (MCDM) techniques, specifically the Analytic Hierarchy Process (AHP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL), to evaluate various strategies for risk reduction in flood-affected infrastructure. The study highlights the importance of structural design improvement, long-term funding, and community education. These insights are crucial for policymakers aiming to develop resilient infrastructures that can withstand future floods.

The seventh paper, written by Ghazali et al., develops a construction safety audit model using the Business Process Model and Notation (BPMN) to enhance stakeholder communication and collaboration, ultimately improving safety outcomes and reducing accident rates. The study's

implications suggest that construction companies can benefit significantly from integrating BPMN into their safety audit processes.

The eighth paper, written by Rahmanea and Rarasati, discusses the role of stakeholder involvement in enhancing safe drinking water infrastructure using an Interpretative Structural Modeling (ISM) approach. The study highlights the importance of effective stakeholder management in achieving sustainable development goals (SDGs). This research provides a comprehensive understanding of the complexities of ensuring access to safe drinking water in Indonesia.

The ninth paper, written by Fadli et al., discusses the relationship between construction safety plans (CSPs), knowledge management (KM), audit processes, information systems, web integration, and BIM with construction safety performance. The study provides a framework for integrating these elements to enhance construction safety practices. The findings reveal significant relationships between the studied variables, indicating the critical role of technological integration in achieving optimal safety results.

We hope this edition may convey new insight and knowledge that benefit our readers. We welcome any comments or inquiries that you may have concerning the direction and the content of this journal. We invite you to join our venture by sending your work for future consideration.

Warmest regards from the Editorial Office,

Prof. Mohammed Ali Berawi
Editor-in-Chief

Dr. Mustika Sari
Managing Editor

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Managing Editor

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DEVELOPING JETTY STRUCTURE DESIGN PROCEDURE USING COMPUTATIONAL DESIGN AND BUILDING INFORMATION MODELLING TO IMPROVE TIME PERFORMANCE AT THE SCHEMATIC DESIGN STAGE

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ABSTRACT

The construction sector faces persistent productivity challenges, significantly hindering the efficiency of design workflows. Computational Design (CD) and Building Information Modeling (BIM) offer potential solutions. CD enables the exploration of parametric design alternatives, while BIM enhances collaboration, visualization, and decision-making through comprehensive 3D models. This study aimed to investigate the processes and activities involved in the structural design of jetties during the schematic design phase using CD and BIM and to assess the impact of these activities on design time performance. A comprehensive analysis of secondary data was carried out, interviews were conducted with design experts, and quantitative analysis using SPSS29 was employed to assess the impact of the design procedures on design time performance. The investigation identified nine critical business processes in the structural jetty design using CD and BIM, comprising 37 design activities. The impact assessment revealed two crucial factors, CD-BIM Design Activities, and Internal Design Review, showing that incorporating computational design and BIM processes into structural design procedures significantly improved design time performance. The research highlights the transformative role of CD and BIM in streamlining structural design processes, marking a significant advancement in the pursuit of efficiency within the civil engineering sector.

Keywords: Building information modelling; Computational design; Jetty structure design; Design time performance

1. INTRODUCTION

Jetty structures are significant in coastal areas as they facilitate the movement of goods and ferries between land and ships when transporting raw materials (Gaikwad & Chore, 2018; Pandey et al., 2019; Rajaram et al., 2017). Designing a jetty requires a comprehensive analysis of various factors, including static dead loads, dynamic live loads, wind forces, and marine influences such as wave and mooring loads (Gurnani et al., 2019). Additionally, challenges in jetty structure design include conformity with design specifications, seismic requirements, clarity of design and equipment specifications, and data incompleteness (Joubert & Pretorius, 2020).

Productivity in the construction sector is lower compared to the manufacturing sector, and the average economic productivity is also lower (Barbosa et al., 2017). Several factors contributing to reduced productivity include information loss during preceding phases (Eastman, 2008), lack of established techniques, standards, or guidelines (Seidita et al., 2017), unrealistic project deadlines, insufficient staffing, poor project management (Love et al., 2012), absence of integrated interdisciplinary design (Malykha et al., 2017), concealment of design deficiencies,

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clients need more expertise, have minimal technology implementation (Mujumdar & Matsagar, 2017), and have data-deficient decision-making (Khudhair & Li, 2020). These obstacles affect the planning process of jetty construction, thereby worsening productivity issues in the construction sector.

Engineering design generally consists of three main sequential phases: conceptual, basic/schematic, and detailed design (Horikx, 2017). The design phase in Architecture, Engineering, and Construction (AEC) projects is critical (Renev, 2018), as decisions made during early planning significantly influence a project's cost, performance, reliability, safety, and environmental impact (Hsu & Liu, 2000). Typically, the schematic design phase focuses on formulating a comprehensive action plan for the building, including planning, design, and adherence to the client's budget. This phase encompasses all essential engineering aspects, materials, equipment, systems, and spaces required for the construction and subsequent operation of the project (Garg & Dewan, 2022).

Computational Design (CD) revolutionizes civil engineering by leveraging computer-based techniques, such as parametric design, to improve the efficiency, accuracy, and innovation of structural and infrastructural design and analysis. Case studies show that CD enhances the development of residential complexes, stadiums, and various structures by efficiently handling complex geometries, extensive projects, and successive design modifications (Debney et al., 2022). Building Information Modelling (BIM) provides detailed digital representations comprising every stage of an engineering project's lifecycle. BIM streamlines construction projects by offering precise quantity and cost estimations through direct extraction features (Vassen, 2021), serving as a central information hub that ensures stakeholders access the latest and most accurate project data, thereby guaranteeing the creation of consistent and reliable drawings (Disney et al., 2022). BIM collaborative tools enable real-time sharing and updating of project information among architects, engineers, and contractors, which is crucial for minimizing errors and maintaining a cohesive vision throughout the project lifecycle (Ciotta et al., 2021).

Empirical studies highlight the necessity of these advancements, revealing that design-related rework accounts for significant project delays, with an average of 12% of project time dedicated to revisions (Ekambaram et al., 2014). This issue is particularly acute in jetty structure projects, where the complex interplay of structural, geotechnical, and environmental factors intensifies the challenge. Moreover, a survey of industry professionals indicated that over 60% recognize design coordination as a significant barrier in successfully executing jetty projects (Forcada et al., 2017).

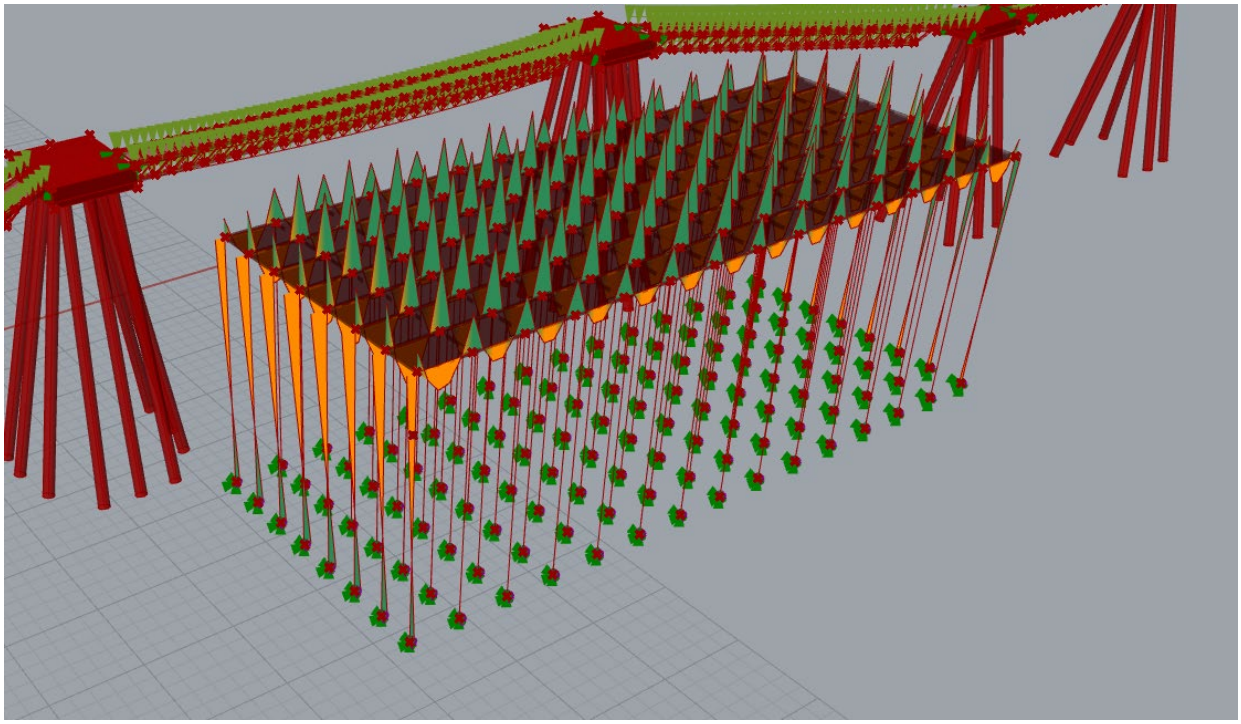
Integrating CD and BIM in engineering design has significantly improved design process efficiency, accuracy, and cost-effectiveness (Caetano & Leitão, 2019; Carroll et al., 2021; Delavar et al., 2020). However, current jetty design practises may not fully utilize the capabilities of both approaches to enhance design time performance. BIM-based quantity take-off (QTO) systems can enhance estimation reliability during the early design stages by focusing on building frames and analyzing the appropriate Level of Detail (LOD), thereby reducing risks and expediting the process (Choi et al., 2015). Established design protocols do not exist that comprehensively incorporate CD and BIM during the early design phase, which is essential for maximizing time efficiency in jetty design (Ma et al., 2021). This study attempts to address the existing gap by investigating the integration of CD and BIM in the schematic design phase of jetty structures to improve design time performance and overall project efficiency.

2. LITERATURE STUDY

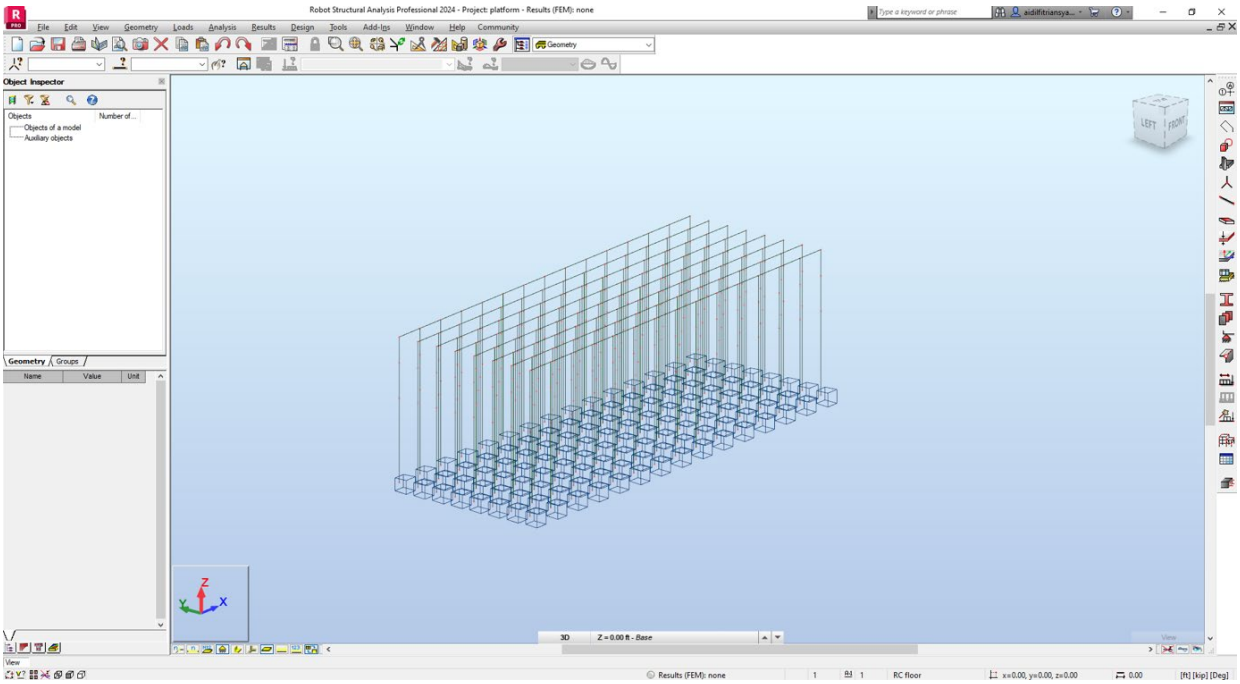
2.1. Computational Design-BIM

CD integrates computational power with design techniques to manage complex geometries and tasks, redefining the design process beyond ordinary automation through digital tools and computational thinking (de Boissieu, 2022). In CD, two distinct programming methods can be used: Textual Programming Language (TPL) and Visual Programming Language (VPL) (Ma et al., 2021). TPL uses text scripts for program development, while VPL adopts encrypted visual elements for the same purpose (Mikaelsson, 2022). In this study, the methods used include Grasshopper, a VPL for Rhinoceros, and the 3D modeling software by Robert McNeel & Associates. The script is divided into three modules: geometry, structural analysis, and BIM.

Specifically, the geometry module defines the foundational geometry using parameters such as jetty length, width, and height. The structural analysis module comprises a script for evaluating structural consequences through the output of the geometry module integrated with the Karamba3D plugin. It is to note that the Karamba3D plugin's output is subsequently exported to Robot Structural Analysis software. The BIM module contains a script for assigning structural elements in Revit software, which are exported through the Speckle Manager interoperability platform. Speckle is distinguished in the AEC industry as an open-source data framework that ensures seamless interoperability across various CAD software platforms, including Rhinoceros and Revit (Poinet et al., 2020). This study transfers three geometry data types to Speckle: Geometry Data I, comprising structural information such as geometry and loads; Geometry Data II, including initial BIM information; and Geometry Data III, incorporating updated BIM information after structural analysis. The Grasshopper 3D Model developed for this study visualizes the jetty, showing the parametric design's adaptability to geometric parameters (see Figure 1).



(a)

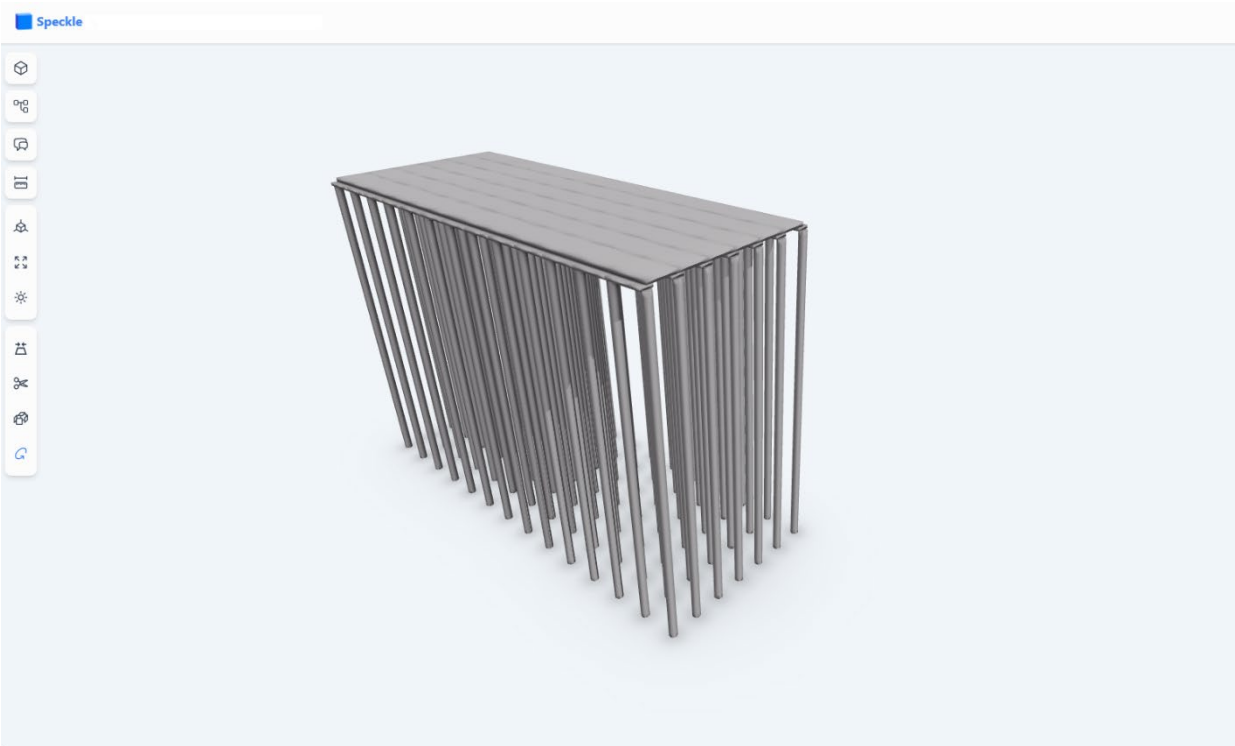


(b)

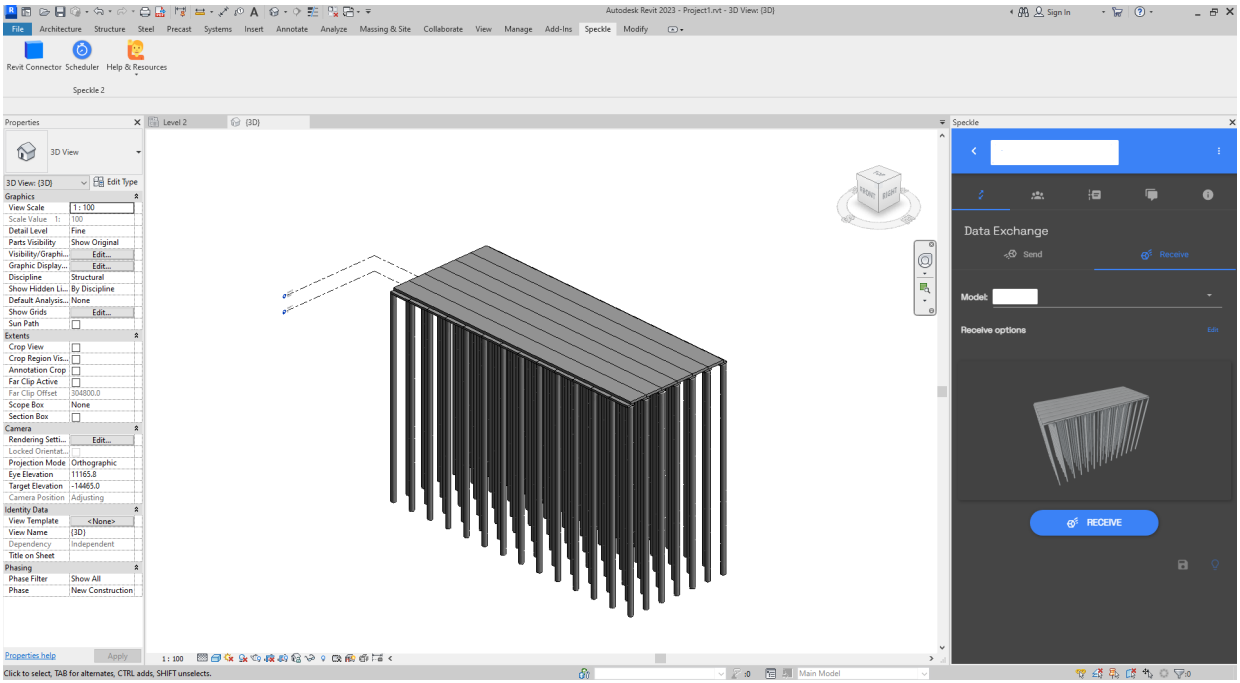
Figure 1 Grasshopper 3D Model Result with Structural Inner Force (a) and Exported Structural Geometry in Robot Structural Analysis (b)

This model, generated through Visual Programming Language (VPL), allows for complex design manipulation via parameters like length, width, and height. The Structural Inner Force visualization, which illustrates stress distribution and potential failure points within the jetty structure, is accompanied by this model, which was analyzed using the Karamba3D plugin. The Exported Structural Geometry highlights the transition to detailed structural evaluation in Robot Structural Analysis.

Furthermore, Figure 2 visualizes the BIM, presenting the 3D Model Result Exported in Speckle Manager, which bridges Rhinoceros and Revit for complex data transfer. This interoperability is essential for preserving design information integrity across software platforms. The figure also displays the 3D BIM Model Result Exported in Revit, marking the design process's integration into a BIM environment. This final model, ready for detailing, further drawing production, and material take-off, demonstrates the efficiency and accuracy of integrating computational design with BIM for jetty structures.



(a)



(b)

Figure 2 3D Model Re Result Exported in Speckle Manager (a) and 3D BIM Model Result Exported in Revit (b)

2.2. Integrating CD-BIM Approaches in Structural Jetty Schematic Design Phase

During the schematic design stage, the designer develops a preliminary concept consistent with the design planning program specifications. Furthermore, the designer arranges the massing patterns and compositions, as shown in the schematic illustrations, to establish the project's

foundational framework. This process is crucial in shaping the project trajectory and ensuring adherence to client objectives, as described by academic sources (Károlyfi & Szép, 2023; Choi et al., 2015). The following explains the process at the schematic design phase of the jetty project, incorporating CD and BIM, as shown in Table 1.

Table 1 Structural Jetty Schematic Design with CD-BIM

Processes	Reference
Basis of Design	(Myrmel & Gudmestad, 2023)
Preliminary Design	(Connor & Faraji, 2013)
Computational design	(Jo et al., 2024)
Structural Analysis	(Connor & Faraji, 2013)
Lower Structural Design	(Connor & Faraji, 2013)
Upper Structural Design	(Connor & Faraji, 2013)
Building Information Modelling	(Caetano & Leitão, 2019)
Cost Estimation	(Alkhuadhan & Naimi, 2023)
Deliverable Handover	(Sadeghi et al., 2019)

3. METHODS

To obtain its objective in examining the impact of the utilization of CD-BIM in design process of jetty structure design on the design time performance, this study used archival analysis and the Delphi method. The Delphi method included collecting data through questionnaires distributed to experts with extensive knowledge, including those with over ten years of experience in jetty design, professionals with at least five years in BIM, and individuals with a minimum of three years in CD, all in the field of construction design.

A 37-item questionnaire, derived from a list of activities and three selected Design Time Performance indicators, was administered to 32 construction sector professionals. These professionals, each with over five years of experience and at least a bachelor's degree, provided quantitative data on the impact of activities on design time performance. After the survey, tests for homogeneity and data adequacy were conducted, followed by correlation, factor analysis, and regression analyses using SPSS 29. The outcome was a model equation describing the correlation between structural jetty schematic design activities with the implementation of CD and BIM on design time performance. The research workflow is illustrated in Figure 3.

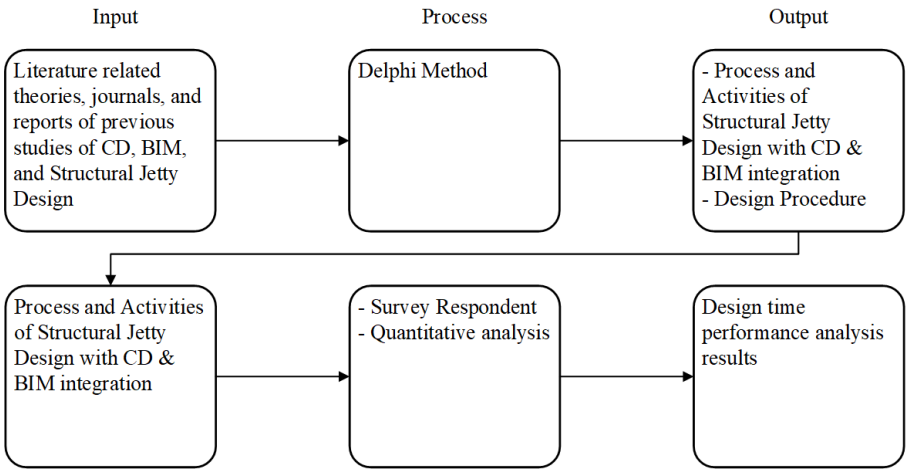


Figure 3 Research Methodology Flow

3.1. Research Variables

This study categorized the variables as independent (X) and dependent (Y). Typically, variable X establishes changes or effects in a phenomenon or situation, and variable Y represents the outcomes or alterations due to the independent variables. The specific X and Y variables examined in this study are shown in Tables 2 and 3 below.

Table 2 Independent Variable (X)

Sub-Factor		Reference
X1.1	Basis of Design	(Myrmel & Gudmestad, 2023)
X1.2	Preliminary Design	(Connor & Faraji, 2013)
X1.3	Computational design	(Jo et al., 2024)
X1.4	Structural Analysis	(Connor & Faraji, 2013)
X1.5	Lower Structural Design	(Connor & Faraji, 2013)
X1.6	Upper Structural Design	(Connor & Faraji, 2013)
X1.7	Building Information Modelling	(Caetano & Leitão, 2019)
X1.8	Cost Estimation	(Alkhuadhan & Naimi, 2023)
X1.9	Deliverable Handover	(Sadeghi et al., 2019)
X2.1	CD Design Process	(Chairiyah et al., 2022; Rawat & Tiwari, 2023; Ajtayné Károlyfi & Szép, 2023b; Pellegrino et al., 2024)
X3.1	BIM Design Process	(de Boissieu, 2022; Vilutiene et al., 2019a; Ciotta et al., 2021; Akhmetzhanova et al., 2022; Kim & Chin, 2019; Vilutiene et al., 2019b; Chen et al., 2022)

Table 3 Dependent Variable (Y)

Sub-Factor		Reference
Y1.1	Client Influence	(Sidwell, 1984)
Y1.2	Design Complexity	(Sidwell, 1984)
Y1.3	Team Organization and Management	(Sidwell, 1984)

3.2. Relation Model Variables and Study Indicators

The study conducted an analysis of the relationships between variables X and Y to determine the causal relationship. The influencing factors and the outcome are presented by variable X and Y, respectively. This study examined the impact of jetty design procedures at the schematic design phase on design time performance, specifically when integrating CD and BIM. Figure 4 depicts the interconnectedness of the variables in a framework X1 represents the Jetty Design Process and Activities, X2 denotes the CD Process and Activities, and X3 indicates the BIM Process and Activities.

Tables 4-6 present the sub-factors identified for each independent variable. These sub-factors were derived from a comprehensive review of relevant literature, including theoretical frameworks, empirical studies, and industry reports. The detailed sub-factors for each variable provide a nuanced understanding of the components influencing the design time performance. By examining these sub-factors, the study aimed to identify the specific elements within the jetty design process that contribute to or hinder efficient design time performance when using CD and BIM approaches.

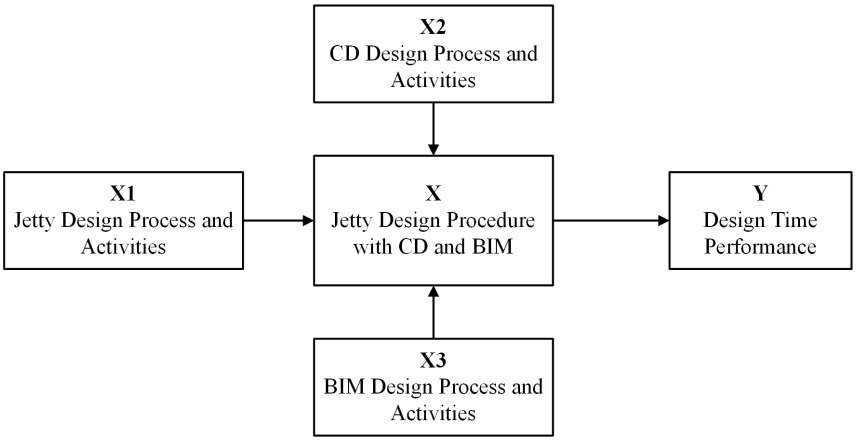


Figure 4 Research Operational Model

Table 4 Sub-Factors of Jetty Design Process and Activities (X1)

	Sub-Factor	Reference
X1.1.1	Define the general site boundary based on the jetty's functional data and client requirements.	(Sorensen, 1997)
X1.1.2	Establish design criteria in line with prevailing standards and client specifications.	
X1.1.3	Collect field condition data from completed field surveys.	
X1.1.4	Prepare a preliminary planning report.	
X1.1.5	Review design progress (external) with the client based on the preliminary report.	
X1.2.1	Determine the layout of structural elements such as slabs, beams, columns, etc.	(Suzuki & Altomare, 2021)
X1.2.2	Specify dimensions and materials for these elements according to design criteria.	(Nolan et al., 2021)
X1.3.1	Receive geometric data (Geometric Data I) from the interoperability platform.	(de Boissieu, 2022; Vilutiene et al., 2019a)
X1.3.2	Inspect received structural models and data (geometry, loading, loads, cases, load combinations, joint support) and adjust if errors are found.	(Suzuki & Altomare, 2021)
X1.3.3	Execute the structural model.	(Mei & Wang, 2021)
X1.3.4	Extract structural analysis results as required.	
X1.4.1	Check soil bearing capacity.	(Udoeyo, 2020)
X1.4.2	Verify the strength of substructures.	
X1.4.3	Assess the serviceability of the structure.	(Mei & Wang, 2021)
X1.5.1	Design reinforced concrete for upper structural elements.	
X1.5.2	Review the design of upper structural elements.	
X1.5.3	Compile a structural report including both upper and lower structures (columns).	
X1.5.4	Conduct an internal review of design progress based on the analysis and design of structural elements.	
X1.5.5	Update the 3D computational design model based on the results from the structural analysis and design of elements.	(Mei & Wang, 2021; Satyanaga et al., 2023)

	Sub-Factor	Reference
X1.5.6	Transfer updated BIM-informed geometric data (Geometric Data III) from the revised 3D model to the interoperability platform.	
X1.6.1	Develop a work method statement.	(Mei & Wang, 2021)
X1.6.2	Estimate construction costs from material takeoffs and work methods.	(Splinter, 2020)
X1.6.3	Draft Outline Specifications.	
X1.6.4	Conduct an internal review of design progress regarding analyzing and designing structural elements, drawings, and construction cost estimates.	(Satyanaga et al., 2023)
X1.6.5	Conduct an external review with the client on analyzing and designing structural elements, drawings, and construction cost estimates.	(Splinter, 2020)
X1.7.1	Prepare the final report.	
X1.7.2	Conduct an internal review of design progress concerning the final report.	
X1.7.3	Submit the deliverable to the client.	

Table 5 Sub-Factors of CS Process and Activities (X2)

	Sub-Factor	Reference
X2.1.1	Conduct computational design modeling using inputs such as layout, dimensions, and materials of structural elements through Grasshopper 3D modeling software with pre-established algorithms.	(Chairiyah et al., 2022; Rawat & Tiwari, 2023)
X2.1.2	Perform conceptual structural analysis on the 3D model using the Karamba3D plugin in Grasshopper software and assess the modeled structure's performance against design criteria.	(Ajtayné Károlyfi & Szép, 2023; Pellegrino et al., 2024)
X2.1.3	Transfer geometric data (Geometric Data I) with structural information and BIM-informed geometric data (Geometric Data II) from the 3D model to an interoperability platform.	(Ajtayné Károlyfi & Szép, 2023; Gerbino et al., 2021)

Table 6 Sub-Factors of BIM Process and Activities (X3)

	Sub-Factor	Reference
X3.1.1	Receive geometric data (Geometric Data II) from the interoperability platform.	(de Boissieu, 2022; Vilutiene et al., 2019a)
X3.1.2	Review the received 3D models and BIM data and adjust when errors are detected.	(Ciotta et al., 2021)
X3.1.3	Conduct BIM model alignment for clash detection.	(Akhmetzhanova et al., 2022)
X3.1.4	Create BIM-based drawings, including plans, elevations, and sections.	(Kim & Chin, 2019)

	Sub-Factor	Reference
X3.1.5	Update the BIM model with Geometric Data III received from the interoperability platform based on structural analysis results.	(Vilutiene et al., 2019b)
X3.1.6	Calculate construction material volumes (material take-off).	(Chen et al., 2022)

4. RESULTS AND DISCUSSION

4.1. Design Procedure Development

The Delphi method was employed to validate the sub-factors and develop the design procedure derived from the literature study for integrating CD and BIM in the Schematic Design Phase of structural jetty design. This structured communication technique involved a panel of five experts: one with proficiency in CD, another in BIM, and three with extensive experience in jetty design consultancy. Each expert had over five years of experience in their respective fields of CD and BIM, while the consultants had at least a decade of experience in jetty design.

The Delphi method consisted of multiple surveys, starting with the initial distribution to gather preliminary opinions on the sub-factors and design procedures. The responses were compiled and analyzed, refining variables based on common themes and points of agreement. Subsequent rounds of surveys were conducted to achieve consensus. This iterative process continued until a robust consensus was reached, resulting in the validated sub-factors and design procedures that formed the Design Procedure, as shown in Figure 5.

Figure 5 showcases the streamlined structural analysis and BIM processes achieved by integrating computational design and BIM into the design workflow. It utilizes geometric data from computational design for structural (Geometry I) and BIM (Geometry II) models, enabling concurrent execution. The workflow mitigates the risk of BIM rework due to design changes induced by structural analysis by designating the computational design model as the single source of truth. This model informs updates to the BIM model through an interoperability platform like Speckle Manager, using the latest geometric data (Geometry III). This approach maintains workflow efficiency without necessitating the restart of the BIM process.

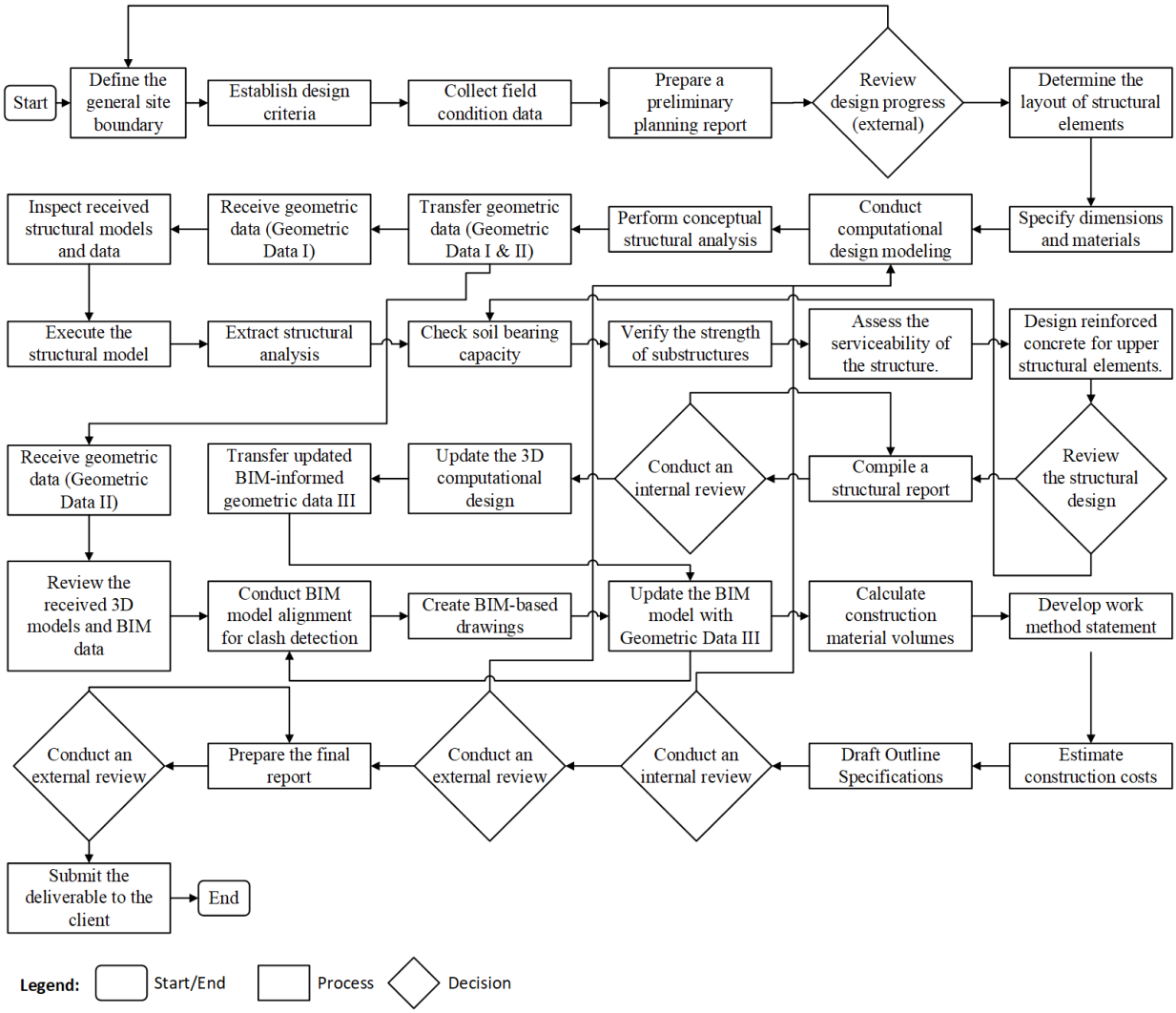


Figure 5 Design Procedure

4.2. Relation of Activities in Structural Jetty Schematic Design with the Implementation CD and BIM on Design Time Performance

4.2.1. Correlation Analysis

Correlation analysis was used to determine the relationship between the independent variables—Jetty Design Activities (X1), CD Design Activities (X2), and BIM Design Activities (X3)—and the dependent variable, design time performance (Y1). In decision-making, a significance (Sig.) value below 0.05 indicated a significant correlation between variables, while a value above 0.05 suggested no correlation. The relevant relationships were denoted by an asterisk (** or *), and the correlation test results are shown in Table 7.

Table 7 Correlation Test Analysis Result

Variable	Correlation Coefficient	Sig. (2-tailed)	N	Variable	Correlation Coefficient	Sig. (2-tailed)	N
X1.1.1	.557**	<.001	32	X1.5.6	.623**	<.001	32
X1.1.2	.367*	0.039	32	X1.6.1	.382*	0.031	32
X1.1.3	.389*	0.028	32	X1.6.2	.588**	<.001	32
X1.1.4	.477**	0.006	32	X1.6.4	.506**	0.003	32

Variable	Correlation Coefficient	Sig. (2-tailed)	N	Variable	Correlation Coefficient	Sig. (2-tailed)	N
X1.1.5	.425*	0.015	32	X1.6.5	.405*	0.022	32
X1.2.1	.438*	0.012	32	X1.7.1	.367*	0.039	32
X1.2.2	.467**	0.007	32	X1.7.2	.423*	0.016	32
X1.3.1	.491**	0.004	32	X2.1.1	.604**	<.001	32
X1.3.3	.498**	0.004	32	X2.1.2	.503**	0.003	32
X1.3.4	.364*	0.04	32	X2.1.3	.668**	<.001	32
X1.4.1	.427*	0.015	32	X3.1.1	.662**	<.001	32
X1.4.3	.365*	0.04	32	X3.1.2	.635**	<.001	32
X1.5.1	.366*	0.039	32	X3.1.3	.545**	0.001	32
X1.5.3	.459**	0.008	32	X3.1.4	.618**	<.001	32
X1.5.4	0.275	0.128	32	X3.1.5	.514**	0.003	32
X1.5.5	.593**	<.001	32	X3.1.6	.491**	0.004	32

4.2.2. Factor Analysis

Given the high dimensionality of the dataset, factor analysis was employed to reduce the number of variables, facilitating subsequent regression analysis in SPSS. Before conducting factor analysis, the Kaiser-Meyer-Olkin (KMO) measure was 0.672, and Bartlett's test produced a significance level of <0.001. These results indicate that the variable sampling was adequate for further analysis.

Table 8 Factor Analysis Results – Rotated Component Matrix

Rotated Component Matrix											
	Component						Component				
	1	2	3	4	5		1	2	3	4	5
X1.1.1.	0.452	0.466	0.415	0.315	0.101	X1.6.1	0.323	0.62	0.174	0.422	0.064
X1.1.2	0.21	0.447	0.072	0.739	0.047	X1.6.2	0.603	0.622	0.085	0.161	0.158
X1.1.3	0.14	0.207	0.081	0.92	0.117	X1.6.4	0.3	0.833	0.317	0.172	0.146
X1.1.4	0.27	0.247	0.698	0.394	-0.14	X1.6.5	0.056	0.744	0.49	0.23	0.194
X1.1.5	0.35	0.29	0.618	0.103	0.392	X1.7.1	0.188	0.55	0.253	0.346	0.18
X1.2.1	0.243	0.283	0.436	0.123	0.614	X1.7.2	0.192	0.781	0.209	0.187	0.313
X1.2.2	0.395	0.406	0.294	0.241	0.689	X2.1.1	0.84	0.115	0.125	0.179	0.192
X1.3.1	0.497	0.293	0.272	0.67	0.061	X2.1.2	0.884	0.039	0.142	0.193	0.047
X1.3.3	0.692	0.142	0.048	0.256	0.478	X2.1.3	0.825	0.187	0.276	0.109	0.066
X1.3.4	0.176	0.106	0.239	0.879	0.296	X3.1.1	0.642	0.187	0.477	0.06	0.204
X1.4.1	0.291	0.115	0.361	0.563	0.574	X3.1.2	0.779	0.336	0.236	0.201	0.351
X1.4.3	0.182	0.347	0.785	0.153	0.323	X3.1.3	0.754	0.271	0.227	0.265	0.428
X1.5.1	0.253	0.307	0.767	0.166	0.323	X3.1.4	0.738	0.297	0.197	0.232	0.45
X1.5.3	0.293	0.566	0.526	0.174	0.276	X3.1.5	0.535	0.368	0.219	0.148	0.619
X.1.5.5	0.876	0.239	0.164	0.116	-0.048	X3.1.6	0.697	0.221	0.154	0.246	0.496
X1.5.6	0.858	0.252	0.187	0.129	0.264						

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization
a. Rotation converged in 8 iterations.

Table 8 shows the factor loadings for each data entry, indicating the formation of five components. This suggests that the SPSS program identified five underlying factors or dimensions: Factor 1, Factor 2, Factor 3, Factor 4, and Factor 5. Naming the latent factor groups or variables was based on the strongest correlation (Table 4) between the variables influencing each factor group and the variable's name within the factor group. The descriptions of these five components can be seen in Table 9.

Table 9 Factor Analysis Grouping Result

Sub-Factor	
Factor 1: CD-BIM Design Activities	
X1.3.3	Execute the structural model.
X2.1.1	Conduct computational design modeling using inputs such as layout, dimensions, and materials of structural elements through Grasshopper 3D modeling software with pre-established algorithms.
X2.1.2	Perform conceptual structural analysis on the 3D model using the Karamba3D plugin in Grasshopper software and assess the modeled structure's performance against design criteria.
X1.5.5	Update the 3D computational design model based on the results from the structural analysis and design of elements.
X2.1.3	Transfer geometric data (Geometric Data I) with structural information and BIM-informed geometric data (Geometric Data II) from the 3D model to an interoperability platform.
X1.5.6	Transfer updated BIM-informed geometric data (Geometric Data III) from the revised 3D model to the interoperability platform.
X3.1.1	Receive geometric data (Geometric Data II) from the interoperability platform.
X3.1.2	Review the received 3D models and BIM data and adjust when errors are detected.
X3.1.3	Conduct BIM model alignment for clash detection.
X3.1.4	Create BIM-based drawings, including plans, elevations, and sections.
X3.1.6	Calculate construction material volumes (material take-off).
Factor 2: Design Review	
X1.1.1	Define the general site boundary based on the jetty's functional data and client requirements.
X1.5.3	Compile a structural report including both upper and lower structures (columns).
X1.6.1	Develop a work method statement.
X1.6.2	Estimate construction costs from material take-offs and work methods.
X1.6.4	Perform an internal review of design progress regarding the analysis and design of structural elements, drawings, and construction cost estimates.
X1.6.5	Conduct an external review with the client on analyzing and designing structural elements, drawings, and construction cost estimates.
X1.7.1	Prepare the final report.
X1.7.2	Undertake an internal review of design progress concerning the final report.
Factor 3: Preliminary Design	
X1.1.4	Prepare a preliminary planning report.
X1.1.5	Review design progress (external) with the client based on the preliminary report.
X1.4.3	Assess the serviceability of the structure.
X1.5.1	Design reinforced concrete for upper structural elements.
Factor 4: Design Criteria	

	Sub-Factor
X1.1.2	Establish design criteria in line with prevailing standards and client specifications.
X1.1.3	Collect field condition data from completed field surveys.
X1.3.4	Extract structural analysis results as required.
X1.3.1	Receive geometric data (Geometric Data I) from the interoperability platform.
	Factor 5: Structural Design and Analysis
X1.2.1	Determine the layout of structural elements such as slabs, beams, columns, etc.
X1.2.2	Specify dimensions and materials for these elements according to design criteria.
X1.4.1	Check soil bearing capacity.
X3.1.5	Update the BIM model with Geometric Data III received from the interoperability platform based on structural analysis results.

4.2.3. Regression Analysis

Regression analysis was conducted to assess the extent to which variable X influenced variable Y. This analysis provided a deeper exploration following the initial correlation analysis. Factors that showed a significant correlation with variable Y and passed the correlation test were considered inputs for regression analysis. The model summary of variables X and Y1, derived from regression analysis using SPSS software, is shown in Table 10, Table 11, and Table 12.

Table 1 Model Summary Variable X and Y

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.652[a]	.425	.401	.36163
2	.808[b]	.653	.622	.28708

a. Predictors: (Constant), Factor CD-BIM Design Activities
b. Predictors: (Constant), Factor CD-BIM Design Activities, Factor Design Review

Table 2 ANOVA Test Results for Variables X and Y

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.319	1	2.319	17.730	<.001[b]
	Residual	3.139	24	.131		
	Total	5.457	25			
2	Regression	3.562	2	1.781	21.609	<.001[c]
	Residual	1.896	23	.082		
	Total	5.457	25			

a. Dependent Variable: Design Time Performance
b. Predictors: (Constant), Factor CD-BIM Design Activities
c. Predictors: (Constant), Factor CD-BIM Design Activities, Factor Design Review

Table 3 Coefficient Values for Variables X and Y

Coefficients					
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.423	.071		62.366	<.001
	Factor CD-BIM Design Activities, Factor Design Review	.305	.072	.652	4.211	<.001

Model		Coefficients Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
2	(Constant)	4.423	.056		78.562	<.001
	Factor CD-BIM Design Activities	.305	.057	.652	5.304	<.001
	Factor Design Review	.223	.057	.477	3.884	<.001

a. Dependent Variable: Design Time Performance

According to Table 10, the regression analysis in SPSS reduced the factors from five to two, indicating that only these factors had significant predictive power. Consequently, the model was refined to focus on these two factors to represent the dataset's relationships accurately. The adjusted R-squared value obtained after outlier elimination was 0.653, indicating that approximately 65.3% of the variance in planning performance could be explained by Factors 1 and 2. Other variables outside the model accounted for the remaining 34.7%.

Table 11 shows the significance of independent variable X on variable Y. In Model 1, the output showed that the significance value was less than 0.05, implying that the factors significantly influenced design time performance.

In Model 2, Table 12 showed that the significance value for Factor 1 was less than 0.05, signifying that the regression model was suitable for predicting the impact of variable X on Y. Consequently, the regression analysis results led to the formulation of a relationship model between Y and X, which was expressed as follows:

$$Y = 4.423 + 0.305\ (\text{Factor 1}) + 0.223\ (\text{Factor 2})$$

The model equation suggested that design time performance (Y1) remained stable without Factor 1 activity due to a positive constant coefficient of 4.423. However, increases in Factor 1 (CD-BIM Design Activities) and Factor 2 (Design Review), with regression coefficients of 0.305 and 0.223, respectively, enhanced design time performance. This outcome showed that CD and BIM activities significantly streamlined the design process.

The regression model's findings align with established research in computational design, BIM, and project management. The positive constant coefficient in the model, representing baseline design time performance, underscores the importance of foundational design practices, which often require dedicated time even in digitally enhanced workflows (Eastman, 2008).

Furthermore, the positive relationship between Factor 1 (Conceptual Analysis of Computational Design) and design time performance echoes previous studies highlighting the efficiency gains of computational design methods. Ciotta et al. (2021) and de Boissieu (2022) emphasize how computational tools facilitate the rapid exploration of design alternatives, optimization of complex geometries, and automation of repetitive tasks, ultimately reducing design time.

Similarly, the positive influence of Factor 2 (Design Review) on design time performance aligns with the findings of Jarratt et al. (2011) and Keusters et al. (2024). These studies demonstrate that rigorous internal reviews, often integrated into BIM processes, can identify and rectify design errors and inconsistencies early in the project lifecycle. Proactively addressing these issues minimizes costly rework during construction, contributing to overall project time efficiency.

The collaborative nature of computational design and BIM, as emphasized by Greenough et al. (2019), further supports the observed results. When stakeholders across disciplines can readily access and interact with dynamic, information-rich models, communication is enhanced, decision-making is expedited, and design conflicts are resolved more efficiently. This

collaborative aspect likely amplifies the positive impact of both Factor 1 and Factor 2 on design time performance.

5. CONCLUSION

Integrating CD and BIM at the jetty structure design schematic stage is crucial for enhancing project time performance. This assertion is supported by the significant influence of specific activities identified in the results.

Empirical evidence concurs with existing literature, consistently accentuating the advantages of CD and BIM. These technologies streamline complex task management, augment geometric precision, and strengthen stakeholder collaborative engagement. Additionally, the model significantly improves innovation and efficiency in design processes, leading to critical time-saving measures in the swiftly evolving construction project design landscape. Incorporating internal review mechanisms further validates the positive impact on design time performance, signifying their essential role in contemporary civil engineering practices.

This research demonstrates the tangible benefits of early integration of CD and BIM in the design phase of jetty structures, providing empirical evidence supporting the theoretical advantages outlined in the existing literature.

Finally, the strategic adoption of CD and BIM and thorough internal review processes constitute a holistic approach for civil engineering entities striving for enhanced design time performance. This method reflects current scholarly discourse and provides a practical avenue for improving the quality and efficiency of the design stages in construction.

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A COMPARATIVE STUDY OF LOCAL AND GLOBAL CONSTRUCTION MATERIAL SOURCING STRATEGIES FOR ROAD PROJECTS IN NIGERIA

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ABSTRACT

This study is a comparative analysis of local and global sourcing strategies to determine the impact of strategic material sourcing on road construction project performance. The study aimed to evaluate the effects of material-sourcing strategies on the performance of road construction companies in Nigeria. A mixed-methods approach was used, incorporating both qualitative and quantitative research. Data collection involved sampling techniques using structured questionnaires and oral interviews. Regression analysis evaluated the relationship between strategic material sourcing and road construction performance. The results revealed that 87.5% of the materials used by road construction companies in the study areas were sourced from the local market, which indicates a high dependence on local resources and substantial investments and purchases within the local economy. Additionally, it was shown that local material sourcing was advantageous over global sourcing in terms of quick delivery and cost savings on road projects. However, the study also revealed that global material sourcing was necessary for projects requiring advanced and higher-quality materials. The study concludes that a high percentage of domestic material sourcing is essential for boosting the Nigerian economy through industrialization, employment generation, and a robust and self-sufficient economy. It is recommended that both government and private material suppliers explore ways to enhance the quality and availability of local road construction materials through advanced manufacturing technologies to improve service delivery by road project contractors. Furthermore, expanding the existing road material procurement process could create opportunities for construction companies beyond the local area and foster healthier competition among them by leveraging economies of scale.

Keywords: Comparative study; Global and local materials; Road construction projects; Sourcing strategies

1. INTRODUCTION

Sourcing construction materials for road projects can be a complicated process. It often includes, but is not limited to, material procurement, delivery, recognizing and defining needs, choosing vendors, ordering materials, receiving and inspecting supplies, auditing invoices, closing orders, and handling and storage of materials. Material procurement particularly requires specialized skills due to its technical nature (Alhammadi et al., 2023; Ibegbulem & Okorie, 2015). Furthermore, the rising costs of construction materials and project implementation have become common issues in Nigeria. Consequently, effective material sourcing strategies can bring considerable cost savings to construction projects (Marques et al., 2023; Ajayi & Oyedele, 2018; Amusan et al., 2017).

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Understanding the requisite material inputs for road projects will help project managers in successful sourcing and enhance project outcomes.

An on-site optimization sourcing strategy has the potential to improve overall road construction project outcomes while also reducing the costs associated with time and material losses. Material sourcing encompasses material supply, storage, handling, planning, implementation, and oversight (Logistics et al., 2020; Dong & Wang, 2018; Linden & Josephson, 2013). Difficulties arising from inadequate material sourcing include errors in ordering materials, issues with ordering small items, delays in material delivery, problems related to material transportation, handling, and storage, production of faulty materials, and general poor resource control (Albert et al., 2021; Muhammed & Saidu, 2021; Gulghane & Khandve, 2015).

This study fills knowledge gaps as there has been little research on operational performance, infrastructure quality, and material sourcing strategies for road construction projects in Nigeria. It aims to evaluate the sourcing of road construction materials, both locally and internationally, to achieve cost-effective operations, reduce risk, and improve the operational performance of road construction organizations. The specific objectives of the study are as follows: (1) to examine the relationship between local sourcing of road construction materials and the sourcing strategy deployed; (2) to determine the relationship between global sourcing of road construction materials and the sourcing strategy deployed; and (3) to assess the relationship between the performance of road construction projects and identified project performance indicators.

The following three null hypotheses were developed and tested based on these objectives. There is no statistically significant relationship between the local sourcing of road construction materials and sourcing strategy (Ho1), there is no statistically significant relationship between the global sourcing of road materials and sourcing strategy (Ho2), and there is no statistically significant relationship between the performance of road construction projects and identified project indicators.

This research is limited to rural road projects and intra-/intercity double-lane expressways within rural and semi-urban areas. Its scope does not include superhighways and multiple-lane road projects. Future research is recommended for superhighways and multiple-lane road projects.

2. LITERATURE STUDY

Roads are critical to harnessing the potential of developing economies by linking different clusters of economic activities (Adebanjo et al., 2023; Foster et al., 2023; Vahed et al., 2023; Ajiboye et al., 2021; Ogbu & Adindu, 2019). In recent years, there has been an increasing emphasis on road construction materials sourcing strategies to ensure the quality and cost-effectiveness of construction projects. Oluwajana et al. (2022) and Mishra and Koju (2020) assert that the cost attribute is a major determinant of construction projects. The cost of materials is a major factor in the success of a project, and proper sourcing strategies can help minimize costs and improve the quality of the project. Materials sourcing for road construction projects requires careful consideration of various factors, such as productivity, profitability, cost, schedule performance, customer and contractor satisfaction, technological capability, low/zero defects, cash flow, and quality.

Therefore, materials' availability, quality, cost, and delivery time must all be considered when sourcing materials (Awaad et al., 2024; Kannan et al., 2013). Additionally, environmental regulations, local regulations, and resource availability must also be considered. The most common road construction materials include asphalt, concrete, gravel, stone, and steel. Asphalt

is the most widely used material, as it is relatively cheap, durable, and easy to install (Kumar & Pal, 2018). Asphalt can be used in various applications, including roads, driveways, and parking lots. Concrete is another commonly used material for road construction. Concrete is strong, durable, and inexpensive (Kumar & Pal, 2018). However, using concrete in road construction can be labour-intensive, as the material must be laid and compacted properly to be effective. Gravel, stone, and steel are also commonly used materials for road construction. Gravel is usually used for roads in rural areas, as it is cheaper and easier to install than asphalt or concrete. Due to its strength and durability, stone is used for road construction in urban areas (Kamal & Bas, 2021; Kumar & Pal, 2018), while steel is used for bridges or other structures requiring higher strength and durability.

Research into the strategic sourcing of materials for road construction has been conducted, with few studies addressing their impact on organizational performance. Bernard and Willy (2017) revealed that procurement processes, communications, risk occurrences, and project financing contribute to completing construction projects. In a different study, Wang'Ombe (2017) investigated the profitability effects of sourcing as a supply chain function. Other researchers have examined material procurement and its impact on the performance of African road construction projects. Tougwa (2015) examined the issues and challenges associated with obtaining quality construction in Africa, concluding that insufficient capacity and corruption were two major issues faced in African construction projects. Sarpong (2017) studied the impact of strategic material sourcing on construction performance, comparing domestic and overseas sourcing strategies. They all concluded that when sourcing materials for road construction projects, it is important to consider cost, quality, availability, and delivery time factors. They also stated that environmental and local regulations must also be considered. By following proper sourcing strategies, construction projects can be completed cost-effectively and on time.

3. METHODS

A descriptive research design was used in this study, utilizing a simple random sampling technique to distribute questionnaires to users. Data were collected from both primary and secondary sources. A total of 60 questionnaires were employed for primary data collection, with a predetermined proportion from Alexi Construction Company Limited, comprising fourteen (14) site engineers, five (5) project managers, twenty-four (24) trade foremen, four (4) purchasing officers and procurement managers, four (4) storekeepers and inventory managers, and three (3) heavy-duty truck drivers, resulting in a total of 54 respondents to gather data to achieve the study's objectives. Secondary data were obtained from existing sources such as journals, the internet, and other research works related to the area of research. Descriptive statistics and regression analysis assessed the relationship between material sourcing and construction operations performance. The descriptive statistics included the mean and standard deviation, while regression analysis helped infer the response variable's dependence on the predictors. Tools in SPSS and Microsoft Excel software were used to generate tables with frequencies and percentages for descriptive analysis, providing proper visualization of the descriptive statistics.

Patigi Local Government Area (LGA) in Kwara State was used as the study area (see Figure 1), located at Latitude 8.7285100 and Longitude 5.7556100. Campanian and Maestrichtian sediments, mostly sandstone, cover the area. Granite-gneiss rocks make up the basement rocks (Geonames Geographical Database, 2016). As such, the area's geology is well-suited for sustainable road construction. Alexi Construction Company (ACC), established in 1981 as a Limited Liability Company, was used as a case study due to its long operational history

spanning 42 years in Nigeria. The company was registered under the Federal Ministry of Works Registration Board in 1982 as a wholly owned indigenous company. Their services include building construction, civil engineering works, renovations, interior and exterior designs, landscaping, and procurement. ACC comprises eight major departments: metal and carpentry, post-construction management, procurement and supply, exterior and interior, building and engineering, water and plumbing, electrical engineering, and mechanical engineering. These departments are responsible for roofing buildings, fixing bridges and offshores, maintaining roads, renovating dilapidated houses, supplying materials and machinery for construction, and furnishing interiors and exteriors.

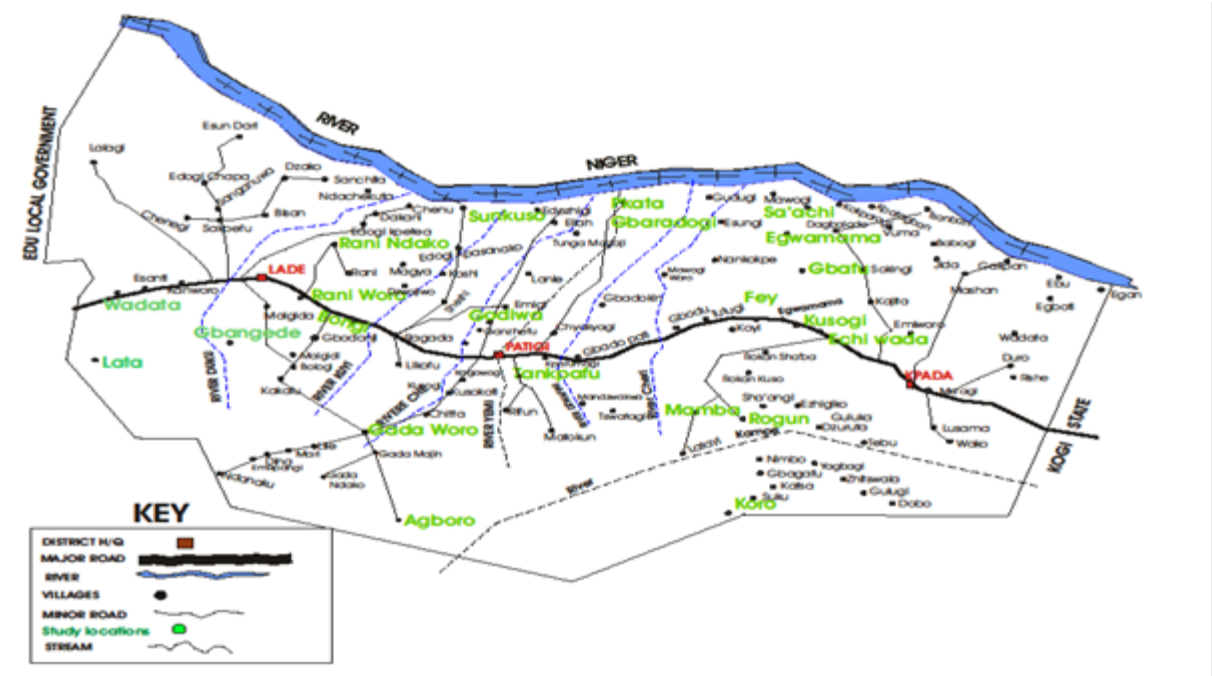

Figure 1 Road Network of Patigi Local Government Area, Nigeria
(Source: Aderibigbe et al., 2017)

4. RESULTS AND DISCUSSION

4.1 Demographic Characteristics of the Respondents

The demographic background of the respondents was studied in terms of gender, educational background, professional qualification, years of work experience, and type of project undertaken. Of the respondents, 40 (74.1%) are males and 14 (26%) are females. There were no female engineers or heavy truck drivers. However, 20%, 50%, and 25% of the project managers, inventory managers, and purchasing managers, respectively, are female. The high disparity in these positions may be due to road construction projects' strenuous and hazardous nature.

Regarding the level of education, 31 (57%) have tertiary qualifications, while the remaining 23 (43%) have primary and secondary-level qualifications. Education was considered an important factor in understanding the sourcing of materials used in construction works. An educated workforce has more knowledge and experience to provide accurate information on road construction materials. As such, their responses were more reliable and informative, and they were better equipped to identify potential sources of quality materials, which helped the company save costs and improve the quality of road construction materials.

As shown in Figure 2, the respondents' professional backgrounds include trade foremen (40%), engineers (28%), project managers (10%), purchasing officers/procurement managers (8%), and storekeepers/inventory managers (8%). This breakdown indicates the types of professionals involved in sourcing road construction materials, either directly or indirectly. The highest percentage of respondents are trade foremen, suggesting a critical role in sourcing materials as they are responsible for the actual operation of the project. Engineers represent 28% of the respondents, highlighting the importance of their technical expertise in the material purchasing process. This implies that the researcher needs to assess the technical capabilities and knowledge of the engineers to ensure that the correct materials are sourced most effectively. Finally, project managers and purchasing officers/procurement managers represent 10% and 8%, respectively. This indicates that the project's organizational structure is also important when it comes to sourcing materials (Young & Osmani, 2013; Caldas et al., 2015). Project and procurement managers and officers will need to be consulted and involved in the purchasing process to ensure that the right materials are sourced (Figure 2).

Figure 2 Professional Background (in percentage)

Regarding the number of years the respondents have spent in the construction industry, 6% have less than 2 years, 30% have 2-3 years, 44% have 4-10 years, 16% have 11-15 years, and 4% have over 15 years of experience. Those with more than 4 years of experience make up a significant portion of 64%. The implications of these findings are far-reaching and should be considered when sourcing materials for road construction projects (Patel & Vyas, 2021). With the majority of industry professionals having considerable experience, it is likely that they are more familiar with suitable sources of materials and better able to assess their quality and suitability for a particular project. Furthermore, they may be more likely to negotiate better prices and secure more cost-effective materials.

Additionally, experienced professionals are likely to be better equipped to make informed decisions regarding the materials used in a project and may provide valuable insights into the potential impact of different materials on the project’s outcome. This can be particularly beneficial for complex projects, where the selection of materials can significantly influence the project's success. Finally, experienced professionals may also have access to a broader range of materials and suppliers (Osmani, 2013). This can be beneficial when sourcing materials for road construction projects, as it allows for a greater variety of options and makes it easier to find the most suitable materials for the job.

4.2 Case Study of Road Construction Projects in Patigi Area

Several types of roads are being constructed in the Patigi area, with rural roads constituting the majority of construction works (50%), followed by intra/intercity double-lane/expressways (40%), and other road works comprising 10% (Fig. 3). Specific examples of rural projects include the Bida/Sacci/Nupeko/Patigi Road, whereas intra/intercity double-lane/expressways include the Asphalt Pavement of Emirs' Road, Patigi, the Kaiama Roundabout, and others such as the Kpada/Patigi Road.

4.3 Sourcing Strategies

In this study, the sourcing strategies (local or international) used by the company to acquire various building materials are determined by percentage. The higher the frequency of the sourcing method, the greater the proportion. The industry's preferred technique for acquiring building materials, whether at the local or international level, is shown in Table 1. Of the 100% responses, the majority of the materials are sourced from local markets, including soil (100%), mineral aggregates (89.9%), cement (96.3%), water (100%), tar (53.7%), iron rods (79.6%), and wooden products (83.3%). In contrast, the industry sources asphalt (51.9%) from the global market. The results in Table 1 are noteworthy and can have significant implications for the sourcing of road construction materials. Local sourcing of materials is generally preferred for its cost-effectiveness and positive impact on the local community.

Table 1 Sourcing Strategies

Construction Materials	Sourcing Comparison	Strategies Frequency	Percent
Wooden Materials	Local	45	83.3
	Global	9	16.7
Soil	Local	54	100
	Global	0	0
Iron Rods	Local	43	79.6
	Global	11	20.4
Asphalt	Local	25	46.3
	Global	28	51.9
Mineral Aggregates	Local	48	88.9
	Global	6	11.1
Tar	Local	29	53.7
	Global	25	46.3
Water	Local	54	100
	Global	0	0
Cement	Local	52	96.3
	Global	2	3.7

(source: Authors' Computation)

However, in some cases, global sourcing is necessary to access certain resources or materials. The results suggest that local sourcing is the preferred strategy for most of the materials used in road construction. Soil, mineral aggregates, cement, water, and wooden materials all had over 80% responses indicating a preference for local sourcing. This implies that road construction materials are best sourced from local suppliers, which can help boost the local economy. However, the results also indicate that asphalt and iron rods should be sourced from the global market. Asphalt is a relatively cheap material and is often only produced in large-scale operations. Similarly, iron rods are often of higher quality when sourced from global suppliers. While sourcing from the global market is more expensive, it may be necessary to provide the best quality materials.

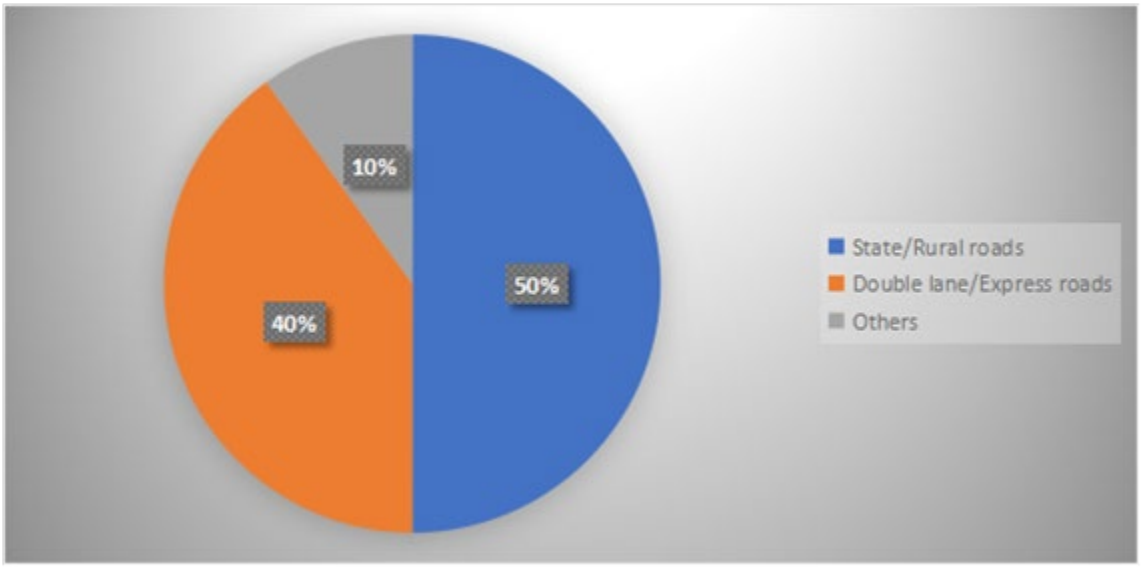

Figure 3 Type of Road Construction Projects Undertaken
(Source: Authors' Computation)

Figure 4 Bida/Sacci/Nupeko/Patigi Road

Figure 5 Kpada/Patigi Road

Figure 6 Kpada/Patigi Road

Figure 7 Asphalt Pavement of Emirs' Road Kaiama Round About, Patigi

4.4 Analysis of the Reasons for Sourcing Construction Materials Locally

Regression analysis, a set of statistical methods, was used to estimate the relationships between the dependent variable and one or more independent variables. This analysis was conducted for two purposes: firstly, to predict the value of the dependent variable based on some information concerning the explanatory variables, and secondly, to estimate the effect of some explanatory variables on the dependent variable.

According to the regression analysis shown in Table 2, the independent variables in the regression model account for 91% of the variation in the response variable. As a result, the model is well suited for regression analysis and gives the best account of how the independent variables in the model contributed. The "F-statistic" of the model is displayed in the second output table of significance. An independent variable (factor) more likely to be connected with the dependent variable than the probability of pure chance is not fundamentally significant for the F-statistic due to random sampling error.

Table 2 Regression Analysis

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0.954[a]	0.911	0.902	0.11874
a. Predictors: (Constant), a_5, a_1, a_3, a_4, a_2				

(source: Authors' Computation)

A regression model provides a function that describes the relationship between one or more independent variables and a response, dependent, or target variable. The significant statistic of the F-test is described in Table 3 as follows: the regression model's significance statistic indicates that there is almost no chance (less than 0.001) that the observed relationships are due to random sampling errors. This confirms that the independent variables significantly contribute to the model.

Table 3 Analysis of Variance

ANOVA[b]						
Model		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
1	Regression	6.929	5	1.386	98.284	0.000[a]
	Residual	0.677	48	0.014		
	Total (Reg + Res)	7.606	53			

a. Predictors: (Constant), a_1, a_2, a_3, a_4, a_5
b. Dependent Variable: Local Sourcing Strategy
(source: Authors' Computation)

Subsequently, the table's ANOVA results show that (F=98.284, P=0.000), indicating a significant relationship between the variables under the measure. Consequently, because $P \leq 0.005$, the null hypothesis (Ho) is rejected, and the alternative hypothesis (H1), which states that there is a significant relationship between the reasons for sourcing construction materials locally and the sourcing strategy, is accepted

The partial regression coefficients and significance tests for each of the model's independent variables are displayed in Table 4. The p-values (less than 0.05) indicate that each variable contributed significantly to the model. The results also imply that the model greatly benefits from the flexibility of the supply chain, the simplification of logistics, the reduction of time and cost of operation, the avoidance of currency risk, the reduction of environmental footprint, and the increase of local income. Notably, the analysis results highlight the importance of a strong supply chain in sourcing road construction materials. Strong control over the supply chain leads to time and operational cost reductions, risk avoidance, and expense savings. Additionally, it increases domestic income, benefiting the local economy.

Table 4 Unstandardized and Standardized Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.311	0.213		2.992	0.326
	(a_1) Strong Supply chain	0.178	0.019	0.425	9.185	0.000
	(a_2) Flexibility and simplified logostics	0.208	0.026	0.299	7.855	0.000
	(a_3) Reduce time and cost of opeartion	0.208	0.031	0.303	6.673	0.000
	(a_4) Avoid currency risk and reduce environmental foot prints	0.171	0.021	0.367	7.993	0.000
	(a_5) Increase domestic income	0.278	0.021	0.627	13.376	0.000

a. Dependent Variable: Local sourcing Strategy

Flexibility and simplified logistics are also important factors, as they can help reduce the amount of time and cost associated with sourcing materials. This is especially crucial for road construction projects, where materials need to be sourced from many different suppliers (Alumbugu et al., 2020; Choudhari & Tindwani, 2017; Phu & Cho, 2014; Tunji-Olayeni et al., 2017). By simplifying the process, companies can save time and money. Reducing environmental footprints can also be beneficial when sourcing materials for road construction projects. Companies can reduce their environmental impact by using more sustainable materials while still obtaining the necessary materials.

Overall, the analysis's findings indicate several key considerations when sourcing materials for road construction, including a robust supply chain, flexibility, streamlined logistics, decreased time and cost of operation, avoidance of currency risk, and enhanced domestic income. Companies should consider these factors when sourcing materials for their projects. Doing so can help them save money, reduce their environmental footprint, and support the local economy (Fernandez & Padgett, 2019).

4.5 Analysis of the Reasons for Sourcing Construction Materials Overseas

The independent variables explain the R Square value, which represents 95% of the total variation in the regression model in Table 5. This shows that the model is well-suited for regression analysis and provides the best explanation of the role played by the independent variables.

Table 5 Regression Analysis (Model Summary)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.974[a]	0.945	0.902	0.11874

a. Predictors: (Constant), b_1, b_2, b_3, b_4, b_5
(source: Authors' Computation)

The "F-statistic" of the model is displayed in the second output table of significance. This statistic and its significance are typically reported in the regression table, with the most crucial

statistic being .000. An independent variable (factor) that is more likely to relate to the dependent variable than the probability of pure chance is not significant for the F-statistic due to random sampling error.

The significant statistic of the F-test is described in Table 6 as follows: The regression model's significance statistic for the F-test indicates that there is no chance (less than 0.001) that the observed relationships are due to random sampling errors. Accordingly, the ANOVA results in the table show (F=98.257, P=0.000), denoting a significant relationship between the variables. Because $P \leq 0.005$, the null hypothesis is rejected, and the alternative hypothesis (H2), which states a significant relationship between the reasons for sourcing building materials abroad and the sourcing strategy, is accepted.

Table 6 Analysis of Variance (ANOVA[b])

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	6.801	5	1.386	98.257	0.000[a]
	Residual	0.682	48	0.025		
	Total	7.706	53			

a. Predictors: (Constant), b_1, b_2, b_3, b_4, b_5
b. Dependent Variable: Global sourcing strategy
(source: Authors' Computation)

The partial regression coefficients of each model independent variable and the significance tests for each statistic are shown in Table 7. The study affirmed that high-quality goods with a rational price (0.017<0.05), minimizing the total cost of purchasing (0.025<0.05), stable purchasing channel (0.032<0.05), benefit from economies of scale (0.014<0.05), and technological standards and design of materials (0.022<0.05) all have a significant contribution to the model. These findings provide interesting implications for the sourcing of road construction materials.

Table 7 Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.241	0.213		3.992	0.315
	(b_1) Strong Supply chain	0.178	0.017	0.435	9.185	0.000
	(b_2) Flexibility and simplified logostics	0.208	0.025	0.399	7.855	0.000
	(b_3) Reduce time and cost of opeartion	0.208	0.032	0.303	6.673	0.000
	(b_4) Avoid currency risk and reduce environmental foot prints	0.161	0.014	0.367	7.993	0.000
	(b_5) Increase domestic income	0.278	0.022	0.527	13.376	0.000

a. Dependent Variable: Global sourcing strategy

When searching for materials for road construction, businesses should prioritize high quality and reasonable pricing, reduce overall purchasing costs, maintain a steady supply chain, take advantage of economies of scale, and ensure that the materials meet certain technological and design standards. If a company can meet all of these criteria, it should be able to source the best

materials for road construction. Moreover, this analysis serves as a valuable example for other companies looking for materials for different construction projects, as it provides them with an idea of what to look for to find the best quality materials and save on costs (Patel & Vyas, 2011). As such, any company looking to source materials should consider this analysis and tailor it to their needs to ensure they can find the best materials at the best prices.

4.6 Performance Indicator Regression Analysis

From Table 8, the regression model's independent variables account for R Square, which represents 98% of all model variance. As a result, the model is well-suited for regression analysis and provides the best account of the role played by the independent variables.

Table 8 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.990[a]	0.9480	0.976	0.03829

a. Predictors: (Constant), c_{10}, c_4, c_3, c_2, c_8, c_5, c_6, c_1, c_9, c_7

The "F-statistic" of the model is displayed in the second output table of significance. This statistic and its significance are typically reported in the regression table, with the most crucial statistic being 0.000. The F-statistic's significance indicates that there is almost no chance that the observed relationships are due to random sampling error, confirming that the independent variables significantly contribute to the model.

Table 9 Analysis of Variance (ANOVA[b])

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	3.132	10	0.313	213.678	0.000[a]
	Residual	0.063	43	0.001		
	Total	3.195	53			

a. Predictors: (Constant), c_{10}, c_4, c_3, c_2, c_8, c_5, c_6, c_1, c_9, c_7
b. Dependent Variable: Performance of construction operation
(source: Authors' Computation)

The significant statistic of the F-test is described in Table 9 as follows: There is almost no chance (less than 0.001) that the observed relationships are due to random sampling errors, according to the regression model's significance statistic for the F-test. Accordingly, the ANOVA findings in the table show a strong correlation between the variables (F=213.678, P=0.000). As a result, the null hypothesis is disproved, and a new hypothesis (H3) is proposed, suggesting a statistical correlation between construction operation performance and performance metrics.

Table 10 provides tests of significance for each of these statistics and the partial regression coefficients for each independent variable in the model. The data shows that Profitability (c1), Productivity (c2), Customer Satisfaction (c3), Time Schedule Performance (c4), Cost Performance (c5), Contractor Satisfaction (c6), Technological Capability (c7), Low/Zero Defects (c8), Cash Flow (c9), and Quality (c10) all have a significant contribution to the model, with p-values less than 0.05, as displayed in Table 10.

Table 10 Coefficients[a]

Model	Identified Performance Indicators	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.624	0.117		5.345	0.000
	(c_1) Profitability	0.077	0.010	0.281	7.519	0.000
	(c_2) Pproductivity	0.115	0.009	0.425	12.815	0.000
	(c_3) Customer Satisfaction	0.100	0.008	0.329	12.487	0.000
	(c_4) Time Schedulle Performance	0.032	0.007	0.114	4.529	0.000
	(c_5) Cost Performance	0.095	0.009	0.278	10.488	0.000
	(c_6) Contractor Satisfaction	0.104	0.010	0.378	10.325	0.000
	(c_7) Technological Capability	0.064	0.011	0.222	5.594	0.000
	(c_8) Low/Zero Defects	0.128	0.013	0.376	10.202	0.000
	(c_9) Cash Flow	0.035	0.011	0.126	3.287	0.002
	(c_{10}) Quality	0.107	0.012	0.219	8.948	0.000

a. Dependent Variable: Construction performance

When sourcing materials, it is important to ensure the suppliers have the necessary capabilities to meet the project's needs. This includes having the right technology, a good track record of producing quality materials with low or zero defects, and a strong financial background to support the project's cash flow. Additionally, suppliers should have a good reputation for customer satisfaction and contractor satisfaction, as these are key factors in the success of a project. Ultimately, this data suggests that the sourcing of road construction materials should consider all the factors reported in Table 10 to ensure success. All these factors are essential to the project's success, and any suppliers chosen should be able to meet the requirements.

5. CONCLUSION

The study's findings suggest a strong correlation between strategic material sourcing (local or international) and the construction performance of the road construction organization undertaking various rural roads, intra/intercity double-lane expressways, and other road works in the Patigi area. This indicates that businesses in the research area can gain from increased profitability, customer and client satisfaction, low/zero defects, and improved cost and time performance by leveraging the advantages of both local and global sourcing.

The study also found that local sourcing attained the highest number of positive measurement outcomes compared to global sourcing, making it the most effective technique for enhancing construction performance. This research implies that sourcing road construction materials should strategically consider local and global options. Companies should weigh the advantages of local sourcing, such as increased client and customer satisfaction and improved time and cost performance, while also leveraging the benefits of global sourcing, such as access to a wide array of materials and improved quality. Ultimately, combining local and global sourcing will likely result in superior construction performance.

Furthermore, the research indicates that 87.5% of the materials used by the construction company are sourced from the local market, highlighting the significant investments and purchases made in the local economy. Consequently, the research strongly recommends that road project practitioners maximize the strong correlation between strategic material sourcing and construction performance to improve productivity and enhance operational and financial performance.

Road project practitioners should leverage the benefits of both local and global material sourcing to grow their enterprise, particularly regarding profitability, customer and client satisfaction, low/zero defects, and overall time and cost performance. Government and private suppliers should explore ways to enhance the quality and availability of locally made road construction materials, such as through advanced technology, to provide better service to various contractors. Expanding the procurement process could open opportunities for construction companies beyond the local area and foster healthy competition. This would also benefit the local market by creating opportunities to meet the demands of larger construction companies and take advantage of economies of scale.

The research findings suggest that sourcing from the local market has numerous advantages over global sourcing. While the company may need to source globally for certain roads that require advanced and higher-quality materials, the research recommends a high percentage of domestic sourcing for the construction industry to help boost the Nigerian economy through increased gross domestic product. However, considering the high costs associated with road infrastructure constructed with locally made materials, the study recommends further research to assess the standard quality of locally produced construction materials.

The findings also show that the company's primary motivation for sourcing materials from abroad was the higher quality and lower cost of materials available on the international market. Given the dynamic environment of road construction, it is imperative to consider the indices examined in this study. Further study is recommended to explore the role of emerging technologies such as Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) in improving material-sourcing strategies for road construction projects in Nigeria. Additionally, the study suggests that additional research be conducted on other organizations besides Alexi Construction Company for a comparative analysis.

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THE MOST INFLUENTIAL FACTORS ON THE RISK COST ESTIMATION PROCESS OF IMPLEMENTING BIM 5D IN QUANTITY TAKE-OFF FOR GREEN RETROFITTING OF HIGH-RISE BUILDINGS

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ABSTRACT

Green retrofitting aims to guide buildings toward sustainable practices, reducing carbon emissions associated with building operations and construction. This study explores the application of Building Information Modeling (BIM) 5D Quantity Take-Off (QTO) to existing high-rise buildings, focusing on components that enhance the performance of environmentally friendly structures and project management. This research identifies the factors influencing the cost estimation process and examines the risks across various phases, activities, outputs, and utilization of BIM 5D in cost estimation. The study highlights the most influential factors in implementing green retrofitting for high-rise buildings using structured interviews, questionnaires, and expert validation. The analysis demonstrates that BIM 5D QTO significantly impacts the risk associated with cost estimation in green retrofitting processes. The study ranks the criteria based on respondent feedback by employing Relative Importance Index (RII) analysis. The statistical analysis identifies key factors affecting the risk of cost estimation in BIM QTO for green retrofitting of high-rise buildings. These factors include evaluating specifications, defining acceptance criteria, decomposing the high-level Work Breakdown Structure (WBS), inputting sizes and specifications of each work component into the 3D model, integrating scheduling into the 3D model, and establishing a BIM Execution Plan.

Keywords: Green retrofitting; Cost estimation process; BIM 5D-QTO; High rise buildings; Relative importance index

1. INTRODUCTION

By 2040, it is projected that two-thirds of the world's buildings will be existing structures, continuing to generate significant carbon emissions. A substantial goal has been set to reduce the carbon emissions of 20% of these existing buildings by 2030, which is critical for achieving Net Zero Energy (NZE) status by 2050 (IEA, 2022). The construction sector currently contributes to 40% of the annual global carbon emissions, as depicted in Figure 1. Building operations account for 27% of these total annual global carbon emissions, while emissions from building construction materials and processes contribute an additional 13% annually (Why The Built Environment?, 2022).

Failure to address these issues could hinder the primary targets of The Paris Agreement (Why The Built Environment?, 2022). Globally, buildings consume 40% of energy, 20% of water, 40% of natural resources, and produce one-third of greenhouse gas emissions, according to the United Nations Environment Program. To mitigate this impact, it is imperative for all building-related

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activities to prioritize environmental considerations, such as green renovations, as recommended by the International Energy Agency (2022).

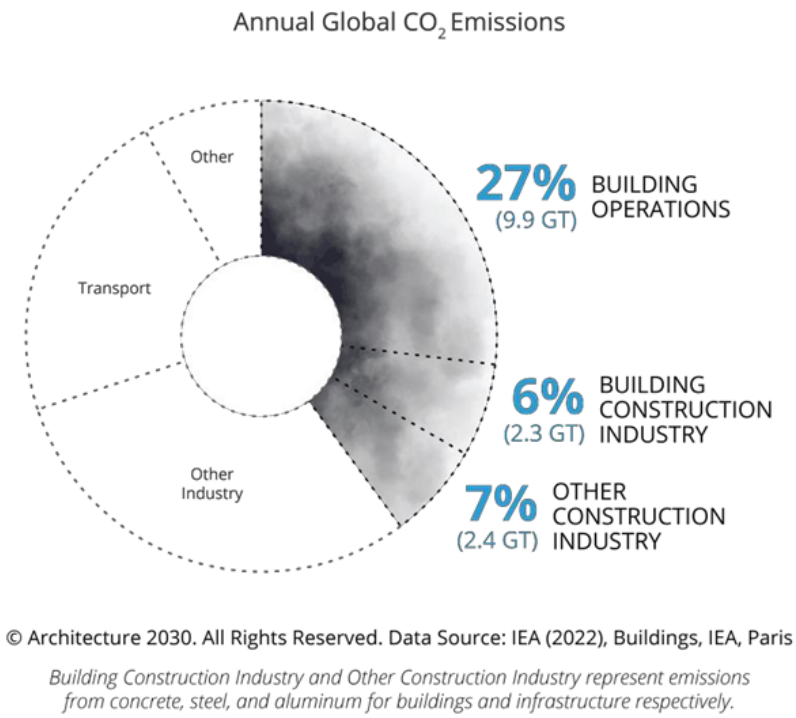

Figure 1 Annual Carbon Emissions
(source: architecture2030.org, 2022)

Green Retrofit, or custom construction, emerges as a highly profitable strategy for reducing carbon emissions in the construction sector. This approach costs only 30% to 50% compared to demolishing existing buildings and constructing new ones, and it is 20% less expensive than building structures that meet green building standards on vacant land.

In addition to using the Work Breakdown Structure (WBS) for building construction work, advanced technology is needed to facilitate effective and efficient building planning. With current technological advancements, the goal is to minimize errors in cost estimation calculations, especially in the construction industry. Most construction companies in Indonesia still rely on conventional applications such as AutoCAD for design, Structure Analysis Program (SAP) for structural calculations, Microsoft Project for scheduling, and Microsoft Excel for cost and volume calculations, which are often done separately (Kamil, 2019). Using fragmented conventional applications frequently leads to construction waste and information delays, resulting in cost and time inefficiencies.

Advancements in information technology, such as big data and cloud technology, enable Building Information Modeling (BIM) to integrate all construction project data, facilitating visualization and management throughout the project lifecycle. BIM 5D can auto-extract and associate with assembly items, ensuring that data is always updated.

However, data indicates numerous challenges in making decisions regarding green retrofit projects, with inaccurate cost estimates being a significant issue. Inaccurate cost estimates often lead to budget overruns during project execution. BIM can address this challenge by providing essential information to facilitate the quantity take-off process in cost estimation (Mahadevi et al., 2018).

The cost estimation process for a green retrofit project, from planning to implementation, utilizes BIM to generate comprehensive project cost estimates. By integrating the WBS for green retrofitting with BIM during the cost estimation phase, it is anticipated that the estimation outcomes will be more accurate. Using BIM in cost estimation can mitigate the risk of incomplete cost calculations for project components, as it provides fundamental information necessary for obtaining accurate estimates (Mahadevi et al., 2018), enhancing the completeness of the information. Furthermore, BIM can minimize the risk of duplicate cost calculations by providing a clearer breakdown of cost components.

Figure 2 illustrates BIM modeling for the Quantity Take-Off (QTO) process. The building design is created in 3D, and detailed building information is provided for the QTO process. Every change and data update is entered into the 3D model, ensuring the QTO process reflects current information. This means that with BIM 5D, the calculation of building volume will be more accurate than with conventional methods.

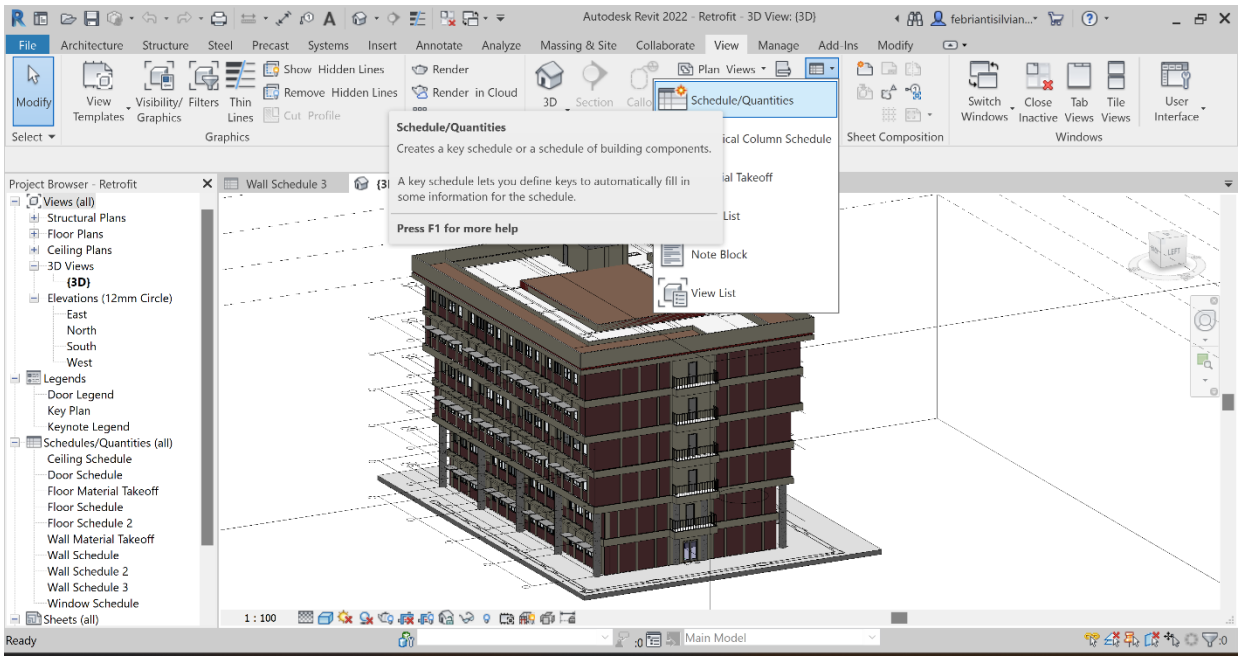

Figure 2 BIM Modelling for QTO Process

This study contributes to green retrofitting for high-rise buildings by identifying factors influencing cost estimation. It also examines the associated risks across various phases, activities, outputs, and risks in utilizing BIM 5D and the cost estimation process. The figure 3 illustrates how to calculate wall-building elements using Revit for the research object. Implementing BIM 5D ensures that the QTO process is streamlined, eliminating any repetition or overlap in the volume calculation of each detailed element.

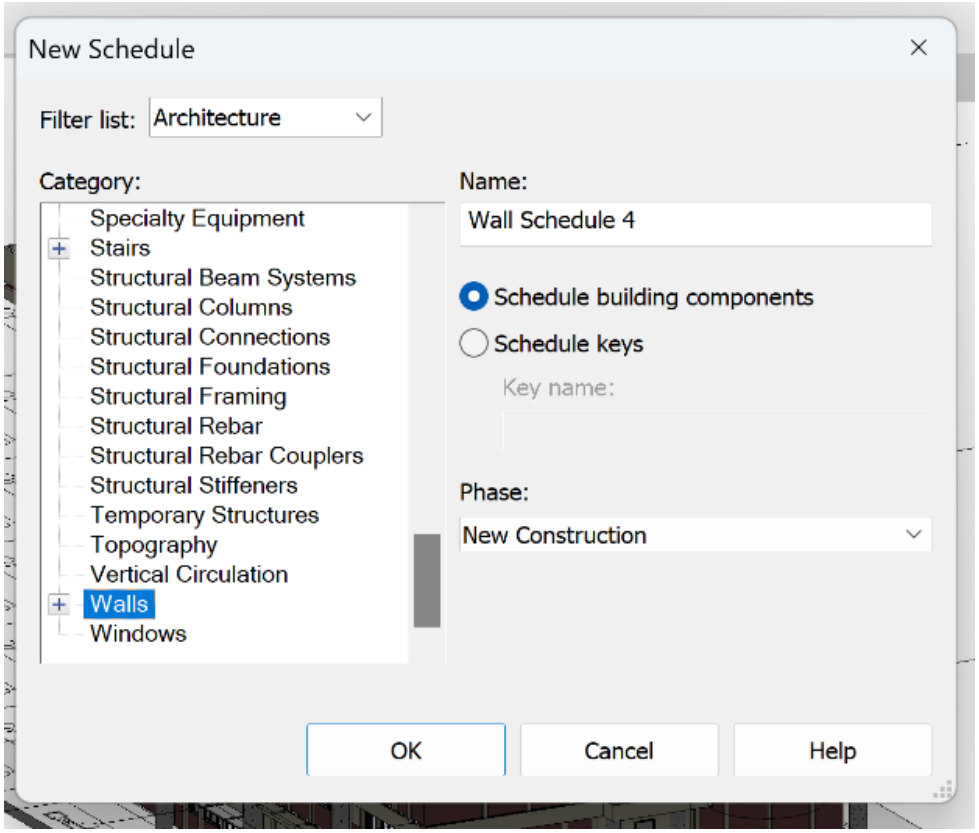

Figure 3 QTO Calculation Process in BIM 5D

Cost factors are integral to the completion of a green retrofitting project. Therefore, during the initial planning phase, it is crucial to account for factors influencing costs to mitigate or minimize potential risks, particularly errors or failures in volume and cost calculations. It is essential to develop mitigation methods and strategies to address these challenges. By doing so, stakeholders can proactively consider these factors at the outset, enhancing the likelihood of project success. According to Mohammadi et al. (2018), the construction sector is characterized by unique, dynamic, and complex characteristics, leading to a higher risk level than other sectors. Construction projects also absorb significant resources, involving many parties in the work. Carelessness in calculating cost estimates during the planning phase can cause substantial losses to various stakeholders.

Despite its benefits, the application of BIM 5D technology in Indonesia is not yet optimal due to risks that hinder the cost estimation process using BIM 5D. Therefore, to ensure that the cost estimation process in green retrofitting high-rise buildings meets the desired goals, it is necessary to identify the factors that give rise to these risks from the beginning.

Previous studies have extensively investigated the factors crucial for calculating quantity and pricing, identifying them as key determinants of project success. Some studies have ranked these factors based on their impact on project performance, while others have proposed mitigation methods for these factors in the QTO estimation and calculation process. However, studies focusing on factors related to the estimation process and BIM 5D QTO in green retrofitting projects are lacking despite widespread implementation in new green building projects. Therefore, this research aims to identify the most dominant factors influencing the risk in the cost estimation process and the implementation of BIM 5D for green retrofitting of high-rise office buildings.

2. LITERATURE STUDY

2.1. Green Cost Estimation Process for Retrofitting High-rise Office Buildings

The cost estimation process entails the systematic steps to estimate the costs required to execute a project, product, or service. Peurifoy et al. (2014) state that a robust cost estimation process is essential for generating accurate cost estimates. While the estimation process is not entirely automated, BIM-based QTO can furnish all the requisite data for creating cost estimates and bills of quantities. However, it remains imperative to assess whether the data extracted from the model accurately reflects the actual building (Monteiro & Poças Martins, 2013).

Cost estimates and budgeting are closely intertwined, each influencing the other. Careful and precise cost estimates are crucial, as they inform comprehensive budgeting, enabling the anticipation of all project costs. In contrast, inaccurate cost estimates can lead to unrealistic budgeting, resulting in financial challenges during project implementation.

2.2. BIM-based Quantity Take-Off

BIM is a comprehensive system, management approach, method, or sequence utilized in project implementation. It integrates relevant information from all aspects of a building, which is then projected into a three-dimensional model (Wong et al., 2010). BIM entails the creation of a 3D digital model (virtual building) containing all pertinent building information. This model is a tool for planning, designing, executing construction, and maintaining buildings and their infrastructure for all project stakeholders.

Before providing cost estimates or commencing a project, estimators require detailed knowledge of the types and quantities of materials needed for completion. This process ensures accurate cost estimates and material requirements while also offering insights into labor costs associated with installation or execution. This crucial process is known as Quantity Take-Off (QTO), which forms an integral part of the estimation process (Husin et al., 2020).

Historically, manual QTO involved reading scale drawings and persisted as the primary method for volume calculations until the early 1980s. Subsequently, in the mid-1980s, new quantity take-off software emerged. Further advancements occurred in the early 1990s with the adoption of 3D drawings, now recognized as BIM 5D QTO (Choi et al., 2015).

Research by Eastman et al. (2011) indicates that the cost estimation process using BIM 5D is easier and more accurate than traditional paper-based estimation processes because BIM 5D will auto-extract, associate with assembly items, and is always updated (see figure 4).

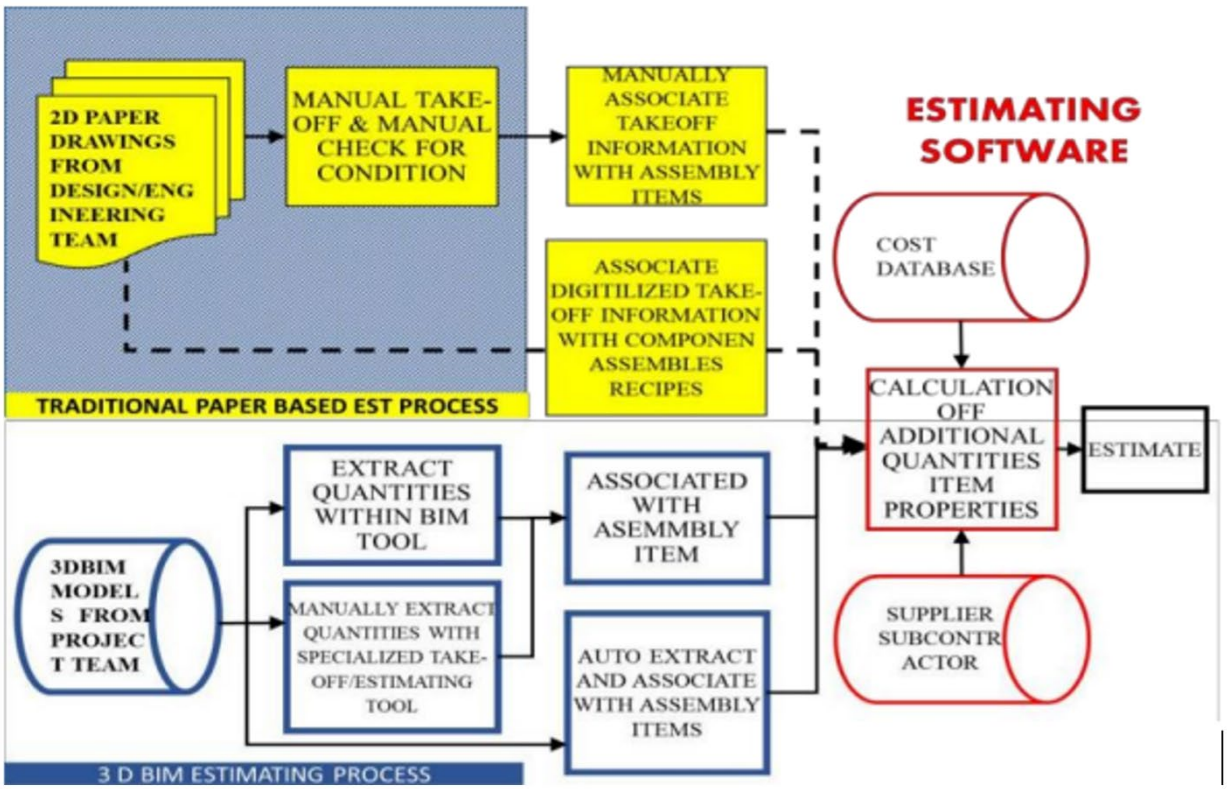

Figure 4 Diagram Comparison of Process between BIM-based QTO and Paper-Based Version (source: Eastman et al., 2011)

2.3. Relative Importance Index

Relative Importance Index (RII) analysis allows for identifying the most significant criteria based on respondents' responses. It is a suitable tool for prioritizing indicators assessed on a Likert-type scale (Rooshdia et al., 2018). The contribution of each factor to the overall delay is examined, and the ranking of attributes in terms of their perceived criticality by respondents is conducted using the Relative Importance Index, calculated through a specific equation (Gunduz et al., 2013). This analytical approach will utilize questionnaires' data, revealing significant factors. The Relative Importance Index will then rank these factors based on their influence as indicated by scores provided by respondents in the questionnaire.

The RII method serves as a means to analyze the most influential factors within the scope of the research. This analytical method involves statistical computations using questionnaire results as input, which are subsequently processed to identify significant factors. The Relative Importance Index determines the most significant factors through a ranking system based on the weighting of scores provided by respondents upon questionnaire completion. Previous research has employed the RII method to ascertain significant factors through computational equations.

3. METHODS

This research employed the quantitative method to determine the causal relationship between independent and dependent variables to obtain its objective. In this approach, all variables influencing the outcome must be controlled except for the predetermined independent variable. The relationship between these variables can be represented as an operational research model, as illustrated in Figure 5..

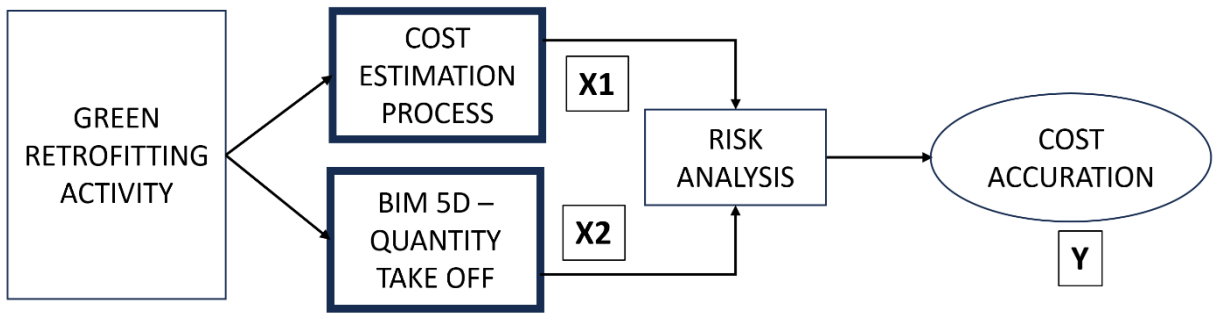

Figure 5 Conceptual Research Model

The methods and techniques used for data collection and analysis in this research are outlined in the accompanying flowchart, depicting the research process employed in this study, which includes literature review, expert validation, identification of process estimation, questionnaire survey, and RII ranking. Additionally, it illustrates the relationship between risk, BIM 5D QTO, and the cost estimation process, highlighting their influence on cost accuracy.

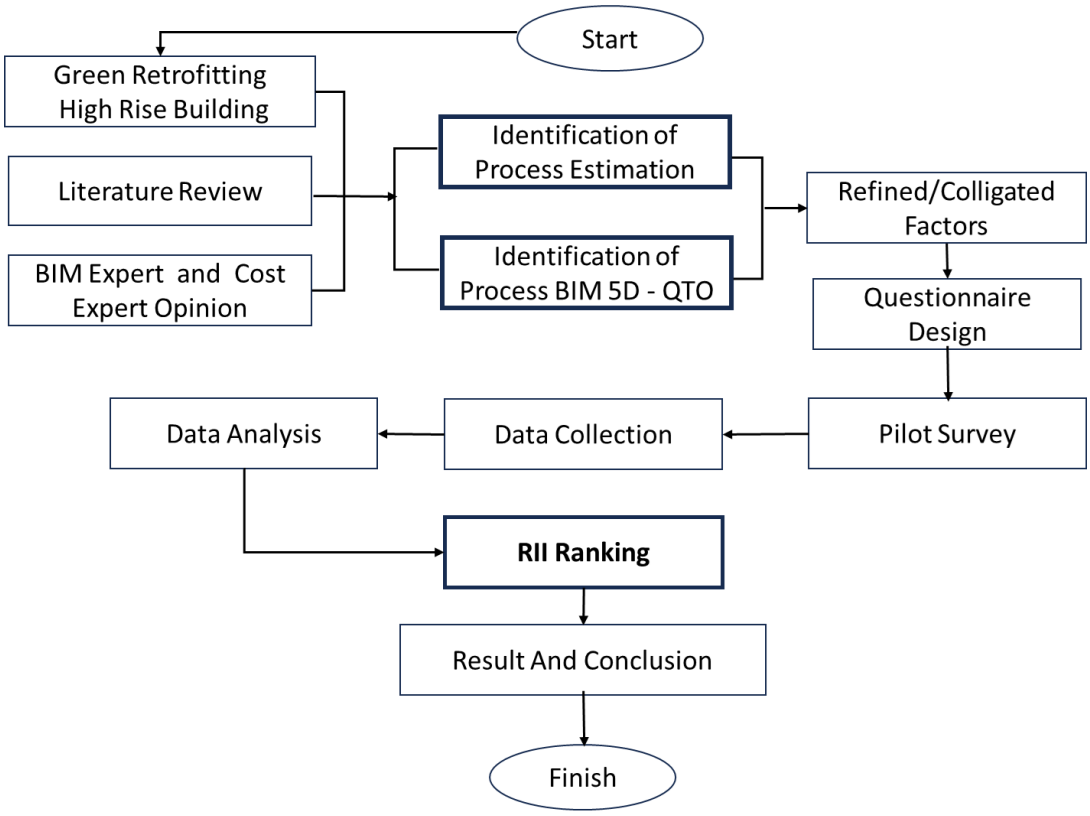

Figure 6 Research Flow Chart

Figure 6 explains that the stages of this research stage begins with identifying each process in cost estimation and BIM 5D. This identification results in key factors in the cost estimation process and BIM 5D. The key factors identified from the literature review were then validated by experts through questionnaires, seeking their responses or suggestions for improvement regarding each application of the BIM 5D process in the cost estimation phase of green retrofitting planning.

The expert responses were analyzed using the Delphi Method to validate the cost estimation process and BIM 5D for the green retrofitting planning stage. Following this, content and construct validation is conducted with respondents representing the construction and green retrofitting fields through additional questionnaires. The data obtained from respondents are analyzed and calculated using RII to identify the most dominant factors influencing the risk in the cost estimation process and the implementation of BIM 5D in the green retrofitting of high-rise office buildings.

3.1. Data Collection and Analysis Approach

To validate the factors influencing cost estimation and BIM 5D implementation, opinions were solicited from nine experts, each proficient in their respective fields. A pilot survey was conducted by disseminating questionnaires to civil engineers via Google Forms and manual distribution. The selected civil engineers constituted the population for this survey.

Table 1 Number of Experts

Expert	Number of Experts	Experience (years)
Project Director	1	16
Construction Manager	2	17
Quantity Surveyor	1	5
Building Expert	1	14
BIM Engineer	2	10
Total	9	

The expert validation process involved a pilot survey of nine expert judgments representing the construction management and green retrofitting sectors. Subsequently, the final questionnaire was distributed to 40 respondents, selected through a random sampling method from a pool of 50 potential respondents (see table 1). These respondents comprised clients/project owners, contractors, consultants, and others. Of these, 57% represented contractors, 39.9% represented consultants, and 3.1% were other respondents, including retired civil engineers or those in different occupations. The respondent population included individuals from the construction and green building fields, ranging from top management positions to engineers, as shown in the table 2.

Table 2 Number of Respondents

Position	Number of Respondents	Percentage
Top Management	3	7.50%
Middle Management	7	17.50%
Modeler	10	25.00%
Engineer	20	50.00%
Total Respondent	40	100.00%

The majority of respondents (82.8%) were male. Among them, 58.9% were over 40 years old. Furthermore, 55.2% of respondents held a master's degree, while 42.3% held a bachelor's degree as their highest educational qualification. A significant portion of respondents (46.6%) reported having more than 20 years of work experience in civil engineering. Regarding the type of organization, 28.8% of respondents were employed in construction companies.

3.2. Data Analysis

The preparation of the questionnaire followed a thorough literature review. Components of the questionnaire, including variables, main factors, and sub-factors, were derived from literature study, considering several previous studies (Dipohusodo, 1996; Kerzner, 1995; Shen, 1997; Stockton & Wang, 2004; Kappelman et al., 2006; Kerzner, 1995; Supriyadi, 2010; Zou et al., 2007; El-Sayegh, 2008; Buranda, 2009; Santoso, 2009; Adnyana, 2017; Indriani, 2022; Akbar, 2023). The subsequent step involved compiling the findings from the literature review into a set of questions to be presented to respondents. Details regarding the sub-factors of this study are elucidated in tabular format, as shown in Table 3 and Table 4.

Table 3 Factor Variables

Main Factors and Sub-Factors (X1: Cost Estimation Process)		Risks in The Cost Estimation Process	
X1.1	Project Scope Statement	X.1.1.1	Errors in determining the scope of work
		X.1.1.2	Lack of communication and collaboration among stakeholders in determining the project scope
		X.1.1.3	Absence or lack of clear and structured planning processes
		X.1.1.4	Lack of monitoring and control of changes occurring in the project scope
X1.2	Baseline Scope	X.1.2.1	Inaccurate planning and scheduling resulting in rework
X1.3	WBS Documents	X.1.3.1	Errors in determining the Project WBS
		X.1.3.2	Lack of monitoring and control of changes occurring in the project WBS
X1.4	Project Scope Boundary/Exclusion (exception) Documents	X.1.4.1	Inability to establish boundaries and control over the project scope
		X.1.4.2	Overlap in the project scope occurs
X1.5	Validated DED (Project Document Update)	X.1.5.1	Discrepancies in data between updated drawing documents/Design and Engineering Drawings (DED) from the owner
		X.1.5.2	Incompleteness of drawing documents/DED obtained from the owner
X1.6	Validated Work Method Documents (Project Document Update)	Incompleteness of work method documents and items in the work method from the owner	
		Lack of experience in handling similar projects	
		Discrepancies in data between technical specifications and drawing documents/DED obtained from the owner	
		Lack of information related to existing project utility data	
		Errors in planning implementation methods	
X1.7	Validated Specification and Technical Documents (Project Document Update)	X.1.7.1	Discrepancies in data between technical specifications and drawings obtained from the owner
		X.1.7.2	Incomplete contract documents, specifications, and drawings from the owner
		X.1.7.3	Lack of experience in handling similar projects
X1.8	Updated WBS Documents	X.1.8.1	Inaccuracy in creating the Work Breakdown Structure (WBS)
X1.9	Activity Resource Estimation Documents	X.1.9.1	Errors in calculating equipment requirements
		X.1.9.2	Errors in calculating material requirements
		X.1.9.3	Errors in calculating labor requirements and productivity

Main Factors and Sub-Factors (X1: Cost Estimation Process)		Risks in The Cost Estimation Process	
X1.10	Updated Price Index List Documents	X.1.10.1	Errors in calculating work item coefficient coefficients
		X.1.10.2	Discrepancies in volume stated in the Bill of Quantity (B.Q.)
		X.1.10.3	Incomplete reference data regarding equipment and labor productivity
X1.11	Budget Plan Documents (RAB)	X.1.11.1	Incomplete reference data regarding unit prices for work
		X.1.11.2	Errors determining unit prices for work
		X.1.11.3	Incomplete list of updated price indices
		X.1.11.4	Lack of data references regarding subcontractors
		X.1.11.5	Errors in calculating work volume
X1.12	Self-Estimated Proce Documents (HPS)	X.1.12.1	Less accuracy in considering the influence of fluctuations in material prices, inflation, interest rates, and exchange rates
		X.1.12.2	Inaccurate risk calculation for location and construction
		X.1.12.3	Inaccurate risk calculation for location and construction
		X.1.12.4	Errors in calculating taxes, insurance, overhead, and profit
		X.1.12.5	Errors in determining unit prices for work
		X.1.12.6	Lack of understanding of project scope by estimators
		X.1.12.7	Estimators lacking qualification
		X.1.12.8	Errors in summarizing
		X.1.12.9	Errors in linking files
		X.1.12.10	Lack of understanding of project implementation methods by estimators

Table 4 Factor Variables for the BIM 5D-QTO Activities

Main Factors and Sub-Factors (X2: BIM 5D)		Risks in BIM 5D-QTO Activities	
X2.1	Project Scope Statement	X.2.1.1	Errors in determining the scope of work
		X.2.1.2	Lack of communication and collaboration among stakeholders in determining the project scope
		X.2.1.3	Absence or lack of clear and structured planning processes
		X.2.1.4	Lack of monitoring and control of changes occurring in the project scope
X2.2	Project Information Documents	X.2.2.1	Errors in data collection
		X.2.2.2	Inaccurate information presentation
		X.2.2.3	Incompleteness of information presentation
X2.3	BIM Execution Plan Documents	X.2.3.1	Lack of understanding of BIM needs and usage objectives in the project
		X.2.3.2	Lack of stakeholder participation in the BEP creation process
		X.2.3.3	Lack of correlation between BEP and project master plan
		X.2.3.4	Lack of resource allocation to support BEP implementation
		X.2.3.5	Failure to consider changes or revisions to the Break Even Point (BEP) that may occur during the project process
X2.4	WBS Diagram	X.2.4.1	Errors in creating the Work Breakdown Structure (WBS)
		X.2.4.2	Failure to consider or understand the project scope thoroughly
		X.2.4.3	Lack of involvement of the core project team in the creation of WBS
		X.2.4.4	Inconsistency in using WBS levels and structures
		X.2.4.5	Inaccuracy in grouping work package details

Main Factors and Sub-Factors (X2: BIM 5D)		Risks in BIM 5D-QTO Activities	
X2.5	Building Information-based 3D Models	X.2.5.1	Incompatibility of software used
		X.2.5.2	Inability to integrate data from various sources into the 3D model
		X.2.5.3	Lack of understanding regarding the methods or technologies used in creating 3D models
		X.2.5.4	Use of non-integrated BIM-based software
		X.2.5.5	Lack of coordination among project teams in 3D modeling
		X.2.5.6	Lack of skilled labor/workforce available
		X.2.5.7	Lack of attention to detail in the early stages of 3D model creation
X2.6	Standardization of Sizes and Specifications for Each Work Component	X.2.6.1	Inaccuracy when inputting dimensions and specifications from 2D drawings into the 3D model
X2.7	Determination of Prices for materials, labor, and equipment for each work component	X.2.7.1	Lack of building component and price-related data
		X.2.7.2	Disregarding differences in price or cost that may occur in different regions or markets
		X.2.7.3	Disregarding differences in specifications or quality of materials and equipment that may be used in the project
		X.2.7.4	Failure to consider risk factors or additional needs in the cost estimation process
X2.8	Specification of Materials Used	X.2.8.1	Inaccuracy in setting the materials used
X2.9	List of Project Work Schedules	Unidentified activities in the plan	
		Failure to consider risk factors or additional needs in the scheduling process, such as weather or material delivery delays	
		Errors in sequencing work activities	
		Inaccurate estimation methods for the duration of each activity	
X2.10	Integrated 3D Model with Scheduling	X.2.10.1	Inaccuracy in linking scheduling into the 3D model
X2.11	Quantities of each work component	X.2.11.1	Inaccuracy in the data input process
		X.2.11.2	High complexity of the BIM model
		X.2.11.3	Incompatibility between the BIM model and the Bill of Quantities documents
		X.2.11.4	The inability of BIM 5D teams to understand and utilize all features and potentials of the software
X2.12	List of quantity results for each work component	X.2.12.1	Changes or modifications to designs during the construction process, requiring changes to the BIM model and bill of quantity calculation
X2.13	Integrated the 3D model with scheduling and costs	X.2.13.1	Limited capabilities of BIM 5D to process non-geometric aspects of the project, such as schedules and budgets

The RII method is utilized to ascertain the significance level of each delay factor. Data collected from the questionnaires is employed to compute the Relative Importance Index, average value,

and standard deviation for each project delay factor. The equation used to calculate the Relative Importance Index is as follows:

$$RII = \frac{\sum_{i=1}^{5} wx}{A \times N}$$

where,

RII = Relative Importance Index
A = 5 (Highest weight)
N = Total number of respondents
w = 1 to 5 (weight given to each factor by each respondent)
x = frequency of answer given for each factor

The weight assigned to each factor by each respondent (1 = Very low significance, 2 = Low significance, 3 = Medium significance, 4 = High significance, 5 = Very high significance) is multiplied by the frequency of answers given to each factor. The total of these values is then calculated. Subsequently, the results are divided by the product of the highest weight (5) and the total number of respondents. The ranking of delay factors is conducted using the RII. The overall rating is calculated by aggregating the responses provided by all respondents. Data analysis in the initial data collection stage involves archival analysis and preliminary validation of variables by experts. Subsequently, the data will undergo processing utilizing the RII technique.

4. RESULTS AND DISCUSSION

4.1. System Performance Benchmarks

To identify the factors influencing the implementation of BIM-Based Quantity Take-Off in high-rise office buildings, researchers utilized the RII statistical analysis method. This approach involved statistical calculations conducted on the questionnaire results, which served as input for determining the significant (influential) factors. The RII method employs a ranking system based on the weighting of values provided by respondents upon questionnaire completion to determine the most significant (influential) factors (see table 5).

Table 5 RII and Ranking of Estimation Process Factors

Sub-Factors			Likert Scale					RII Component			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/(A*N))	
X1.1 Project scope statement	X1.1.1	Describe the scope of the project			1	16	23	182	5	40	0.91	13
	X1.1.2	Describe the results of each product				16	24	184	5	40	0.92	8
	X1.1.3	Describe the acceptance criteria				12	28	188	5	40	0.94	2
	X1.1.4	Project boundary/exclusion (exception)				15	25	185	5	40	0.925	6
X1.2 Images and Specifications	X1.2.1	Review the drawings for the type of construction used				17	23	183	5	40	0.915	9

Sub-Factors			Likert Scale					RII Component			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/(A*N))	
	X1.2.2	Review the work methods used				19	21	181	5	40	0.905	15
	X1.2.3	Evaluate specifications				11	29	189	5	40	0.945	1
X1.3 WBS	X1.3.1	Identify and analyze results and related work				18	22	182	5	40	0.91	14
	X1.3.2	Structure and organize the WBS				17	23	183	5	40	0.915	10
	X1.3.3	Decompose high-level WBS into more detailed low-level components				13	27	187	5	40	0.935	3
	X1.3.4	Compile and assign identification codes for WBS components				17	23	183	5	40	0.915	11
	X1.3.5	Verify the degree of decomposition				17	23	183	5	40	0.915	12
X1.4 Resource	X3.4.1	Identify the resource type			2	16	22	180	5	40	0.9	18
	X3.4.2	Determine resource requirements			1	12	27	186	5	40	0.93	4
X1.5 Unit price	X1.5.1	Determine the price of labor wages			1	13	26	185	5	40	0.925	7
	X1.5.2	Determine the price of materials			1	17	22	181	5	40	0.905	16
	X1.5.3	Determine the price of the equipment.			1	12	27	186	5	40	0.93	5
X1.6 Cost estimation	X1.6.1	Prepare cost estimates for procuring resources				19	21	181	5	40	0.905	17
X1.7 Offer	X1.7.1	Prepare offer documents			2	19	19	177	5	40	0.885	19

Among the seven main factors and nineteen sub-factors, an analysis was conducted to rank and identify the top five factors influencing the risk estimation process activities, as shown in Table 4. The most dominant factors in the risk of the green retrofitting cost estimation process for high-rise office buildings are as follows: Evaluating specifications (1), describing the acceptance criteria (2), decomposing high-level WBS into more detailed low-level components (3), determining resource requirements (4), determining the price of the equipment (5).

Table 6 RII and Ranking of BIM 5 QTO Factors

Main Factors (X2: BIM 5D)	Sub-Factors		Linkert Scale					RII Compenent			RII Index Value	Rank
			1	2	3	4	5	E.W.	A	N	(EW/ (A*N))	
X2.1 Collecting and Inputting Building Information into a 3D Model	X2.1.1	Identify the project scope			1	16	23	182	5	40	0.91	13
	X2.1.2	Compile project information			1	15	24	183	5	40	0.915	9
	X2.1.3	Establish a BIM Execution Plan			1	14	25	184	5	40	0.92	7
	X2.1.4	Structure and organize the WBS			1	12	27	186	5	40	0.93	3
	X2.1.5	Create a 3D model			2	14	24	182	5	40	0.91	10
X2.2 Inputting Building Component Information and Prices for Cost Estimation	X2.2.1	Input the sizes and specifications of each work component into the 3D model			1	16	23	182	5	40	0.91	11
	X2.2.2	Input the price of materials, labor, and equipment for each component of the work				8	32	192	5	40	0.96	1
	X2.2.3	Present the materials that will be used			2	15	23	181	5	40	0.905	12
X2.3 Inputting Information for Time Scheduling	X2.3.1	Arrange overall project scheduling			1	14	25	184	5	40	0.92	8
	X2.3.2	Integrate scheduling into the 3D model				14	26	186	5	40	0.93	4
X2.4 Visualizing Cost Estimation with Time Scheduling	X2.4.1	Quantity Take-Off			1	11	28	187	5	40	0.935	2
	X2.4.2	Generate a Bill of Quantities				15	25	185	5	40	0.925	5
	X2.4.3	Integrate costs of 3D model elements to defined time schedules			4	11	25	181	5	40	0.905	13
					2	11	27	185	5	40	0.925	6

Among the four main factors and thirteen sub-factors, an analysis was conducted to rank and identify the top five factors influencing the risk of BIM 5D QTO activities, as shown in Table 6. The most dominant factors in the risk of implementing BIM 5D QTO in green retrofitting high-rise office buildings are as follows: Inputting the sizes and specifications of each work component

into the 3D model (1), integrating scheduling into the 3D model (2), establishing a BIM execution plan (3), arranging overall project scheduling (4), processing quantity take-off (5).

This research is novel in its focus on the cost estimation process and BIM 5D in the green retrofitting of high-rise buildings, as previous studies have primarily focused on green and new buildings.

5. CONCLUSION

The influence of risk on estimating green retrofitting work and implementing BIM 5D-based Quantity Take-Off activities in high-rise office buildings has been analyzed. Statistical analysis results using the RII method revealed five highly significant factors (influential) in these two activities. Identifying these five highly influential factors will help mitigate the risks in the cost estimation process and BIM 5D implementation.

With the significant influence of these dominant factors, future retrofitting activities can be better mitigated and aligned with desired goals, benefiting stakeholders and promoting sustainability. Addressing risk factors that hinder the attainment of the desired level of cost accuracy when utilizing BIM 5D in the cost estimation process is crucial. One major contributing factor is the high complexity of the BIM model. This risk can be mitigated by providing knowledge, training, and certification to BIM users, particularly estimators and engineers, to optimize the utilization of BIM 5D for the cost estimation process.

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COMPARISON OF THE ACCURACY OF CONTOUR DATA IN PHOTOGRAMMETRIC AND TERRESTRIAL SURVEYS

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ABSTRACT

Understanding and accurately representing the Earth's surface is crucial in various scientific and practical fields. Over the past decades, measurement technology has seen remarkable advancements, offering an array of methods for recording and analyzing Earth's surface with increasing precision and efficiency. Two primary approaches have risen to the forefront of this field: the Digital Terrain Model (DTM) and terrestrial measurements using a Total Station. Although both technologies offer unique advantages and constraints, a comprehensive direct comparison between these two methods often remains an underexplored area. The Digital Elevation Model (DEM) represents the height of the ground surface resulting from acquisition using drones. Ground Control Points (GCPs) are evenly distributed in the study's Area of Interest (AoI) to enhance accuracy and precision. The DEM data is then converted into contour maps and corrected for horizontal and vertical accuracy using the Root Mean Square Error (RMSE) method following the Geospatial Information Agency's standards (Regulation No. 15 of 2014). Terrestrial measurement is a method used to create contour maps using a Total Station to obtain field coordinate data. Terrestrial measurements create contour maps using a Total Station, with field coordinate data corrected by GPS Geodetic methods and compared with aerial photo DEM data. RMSE calculations reveal that DEM data has RMSExy of 0.319 meter (m) and RMSEz of 0.197 m, whereas terrestrial data using the Total Station shows RMSExy of 0.062 m and RMSEz of 0.039 m. Accuracy comparisons indicate that the DEM from aerial photographs has a Circular Error (CE) of 0.485 m and Linear Error (LE) of 0.325 m, while terrestrial data accuracy using a Total Station shows CE of 0.094 m and LE of 0.064 m.

Keywords: Aerial photography; Geodetic GNSS; Terrestrial measurement; DEM

1. INTRODUCTION

Accurately representing the Earth's surface is vital for various scientific and practical applications. Recent decades have witnessed significant advancements in measurement technology, providing numerous methods to record and analyze the Earth's surface with enhanced precision and efficiency. Two leading approaches in this field are the Digital Terrain Model (DTM) and terrestrial measurements using a Total Station. While both technologies offer distinct advantages and limitations, direct comparative studies between these methods are still limited (El-Ashmawy, 2014).

From topographic data, the Earth's surface is represented as a three-dimensional model known as a DTM (Olivier et al., 2021). Natural features such as hills, valleys, rivers, and lakes, as well as man-made structures like roads and buildings, are included. However, to concentrate on the fundamental shape of the ground surface, objects like vegetation and buildings are typically excluded from Digital Terrain Models (DTMs) (Olivier et al., 2021).

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DTMs are indispensable resources frequently employed for visualizing, modeling, and analyzing processes occurring on the Earth's surface. However, obtaining precise models encompassing local-scale landscape features comes with a high cost. Additionally, these models tend to suffer from poor temporal resolution, further complicating their utilization in time-sensitive or dynamic studies (Wiseman & van der Sluijs, 2015).

The creation of terrain models typically involves the extraction of three-dimensional coordinates from one of three main sources: detailed ground surveys, advanced remote sensing techniques, or pre-existing hardcopy or digital topographic maps. The obtained spot elevations or point clouds subsequently undergo processing, employing an interpolation algorithm designed to generate a terrain model. This results in a raster model offering a user-determined spatial resolution, facilitating customization according to specific project needs or user preferences (Wiseman & van der Sluijs, 2015).

The Total Station, a crucial instrument in surveying, is proficient in measuring horizontal and vertical angles and slope distances. Its functionality significantly expedites the measurement process while enhancing the precision of the data gathered. While no direct results were located within the provided resource, additional research across various platforms has revealed insightful discussions on the application of Total Stations in the fields of surveying and architectural mapping, specifically in documenting the features of existing structures (Li, 2010), the effective utilization of Total Station, GPS, and laser scanning equipment (Kattatray, 2021), and the use of Total Station in a combined surveying and scanning device.

Several researchers have conducted studies using unmanned aerial vehicles (UAVs) to calculate the volume of stockpile material, aiming to compare these results with traditional survey methods utilizing Total Stations. The findings indicated that UAV data was more accurate, showing a -0.67% difference from the actual volume, compared to a 2.88% difference with Total Station data (Arango & Morales, 2015; Silva et al., 2020). Additionally, Soto-Estrada (2021) assessed the accuracy of horizontal and vertical aerial photography geometry from UAVs without GCPs. Vertical accuracy is calculated using Aerial Laser Scanning (ALS) data, and horizontal (location) accuracy is calculated by comparing high-resolution orthophoto maps. The statistical analysis confirmed that using Ground Control Points (GCPs) is fundamental to increasing the accuracy of the map products. It also showed that accuracy, understood as comparing the coordinates of Control Points (CPs) measured in the field with their corresponding values estimated in the orthophoto mosaics, depends on the number of CPs and their location.

This research aims to compare the accuracy of the data generated by the Digital Elevation Model (DEM) obtained from Unmanned Aerial Vehicles (UAV) with the elevation data generated by the Total Station. The main issue faced is understanding and determining how much DEM data from UAVs can be trusted regarding their precision and reliability, especially compared to proven, accurate conventional measurement methods such as Total Stations. This research is important because of the rapid development of measurement technology, especially photogrammetry techniques. However, the accuracy and precision of measurement results cannot be ignored.

2. STUDY AREA AND DATA

2.1. Study Area

The research was conducted in Bengkalis District, Bengkalis Regency, Riau Province, Indonesia, specifically at the golf course. This area contains various landscape features, including vegetation, lakes, and roads, though it lacks significant topographic variation, as depicted in Figure 1. The

elevation of the land around the study site ranges from 3 to 4 meters above sea level. The total area of the research location is 16.30 hectares (Ha).

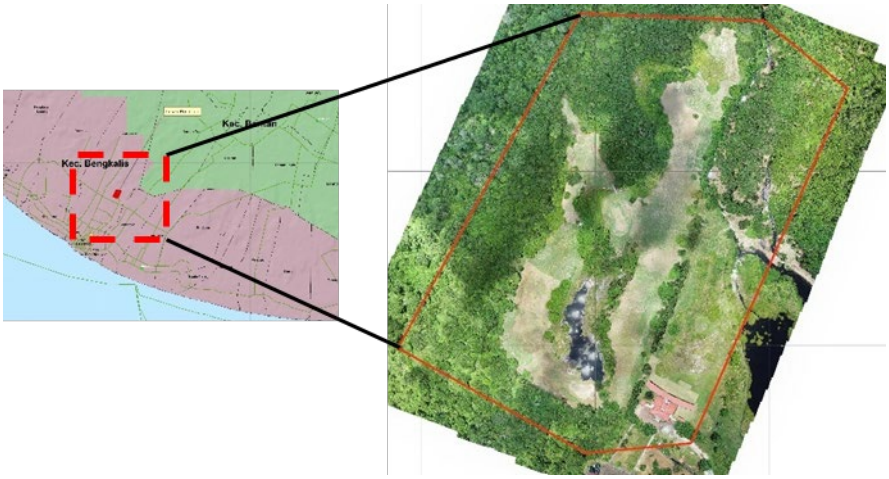
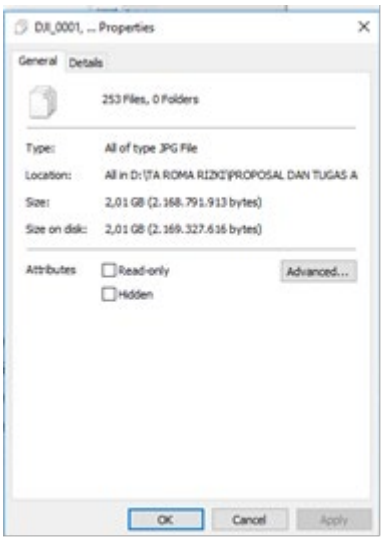


Figure 1 Study Area

2.2. Data

2.2.1 Drone Image Data

In this study, we acquired aerial photo data using a DJI Phantom 4 Pro v2.0 drone (see Figure 2). This process generated 253 photos captured using the nadir method during a single grid flight mission. In this context, the nadir method is a photography technique where the camera is directed straight downward at a 90-degree angle.



(a)

(b)

Figure 2 Information Number of Drone Images (a), Drone DJI Phantom 4 pro Version 2 (b)

2.2.2 Ground Control Point (GCP) and Independent Check Point (ICP)
In this study, the acquisition of coordinates for the GCP and ICP was conducted using the Trimble R8s Geodetic GNSS (Table 1). The observation method employed was Real-Time Kinematic (RTK)-NTRIP with the Indonesia Continuously Operating Reference Station (Ina-CORS) system. Information regarding the BM, Geospatial Information Agency or Badan Informasi Geospasial (BIG)'s CORS station, GCP, and ICP can be found in Table 1.

Table 1 CORS Station, BM, GCP, and ICP Data

Code	Easting (m)	Northing (m)	Elevation (m)
RTCM0173	183465.294	124140.477	6.327
BM 1	180369.388	165286.713	2.872
GCP 3	180371.135	165310.369	2.911
ICP 5	180403.207	165364.192	2.887
GCP 4	180414.886	165417.381	3.416
GCP 5	180384.998	165474.332	3.407
ICP 2	180312.291	165384.938	2.778
GCP 6	180269.711	165346.382	3.466
ICP 1	180236.496	165300.072	3.557
GCP 1	180214.565	165234.189	3.118
ICP 4	180252.500	165183.886	2.550
GCP 2	180297.560	165147.300	2.833
ICP 3	180342.135	165207.039	2.633

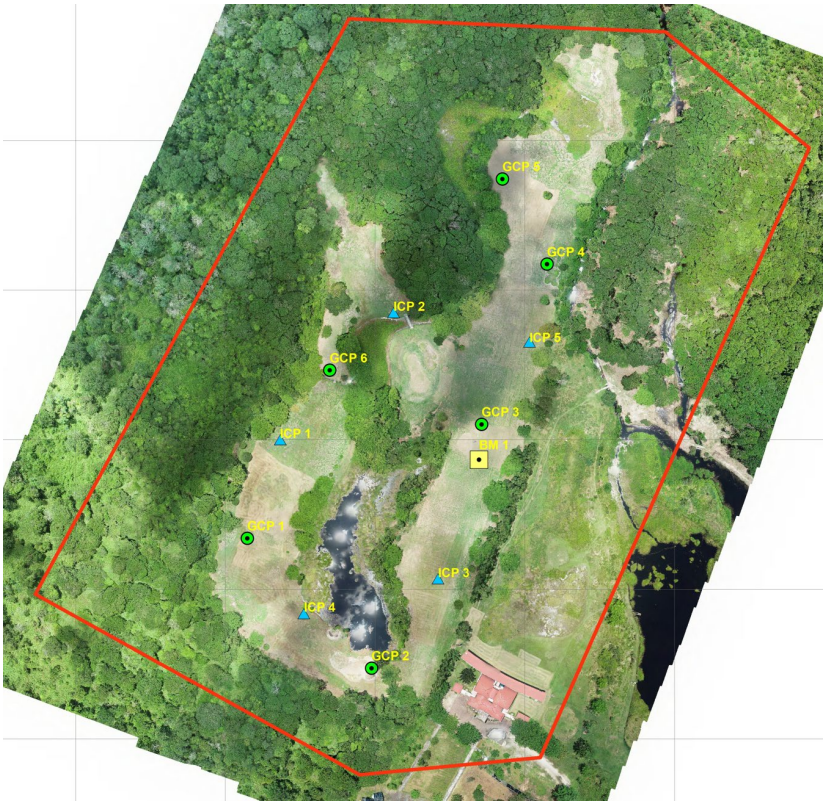
2.2.3 Terrestrial (Total Station) Measurement Data
The terrestrial measurement data acquisition results, carried out using the Focus 5 2" Total Station, consist of coordinate data. This data includes the coordinates of detailed points as well as the coordinates of the GCP and ICP located in the same area (Table 2). Information regarding the BM, GCP, and ICP can be found in Table 2.

Table 2 BM, GCP, and ICP Total Station Data

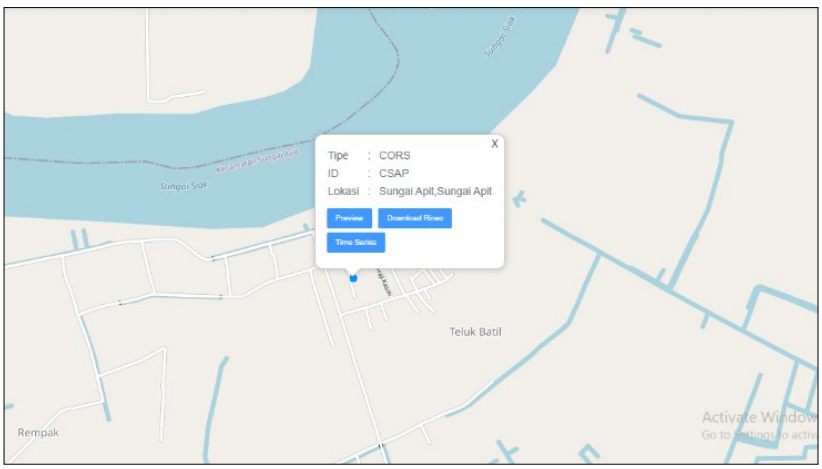
Code	Easting (m)	Northing (m)	Elevation (m)
BM 1	180369.388	165286.713	2.872
ICP 3	180334.030	165210.430	2.597
GCP 3	180373.557	165310.044	2.924
ICP 5	180410.996	165360.198	2.910
GCP 4	180428.146	165411.823	3.434
ICP 2	180322.844	165390.205	2.749
GCP 6	180276.476	165356.296	3.430
ICP 1	180238.727	165313.759	3.513
GCP 1	180210.068	165250.550	2.945
ICP 4	180242.527	165196.636	2.495
GCP 2	180283.545	165155.643	2.769

2.2.4 Distribution of Coordinates GCPs, ICPs, Bench Marking (BM) and Station Cors BIG
GCP and ICP coordinates should be placed in open areas that are easily observable and capable of representing the entirety of the area of interest. This study consists of 6 GCPs and 5 ICPs.

Setting these points aims to obtain accurate values for latitude, longitude, and elevation. The distribution of coordinates, including GCPs, ICPs, Benchmarks, and the CORS Station, is shown in Figure 3.



(a)



(b)

Figure 3 Distribution of Coordinates GCPs, ICPs, and BM (a), Station Cors BIG (b)

3. PROCESSING METHODOLOGY

The research methodology comprises several stages. The first stage is preparing field measurement data, involving the measurement of GCP and ICP coordinates using Geodetic GNSS. The second stage is acquiring aerial photos using the DJI Phantom 4 Pro v2.0 drone. The third stage involves measuring coordinates using a Total Station. The details of the research methodology are provided in Figure 4.

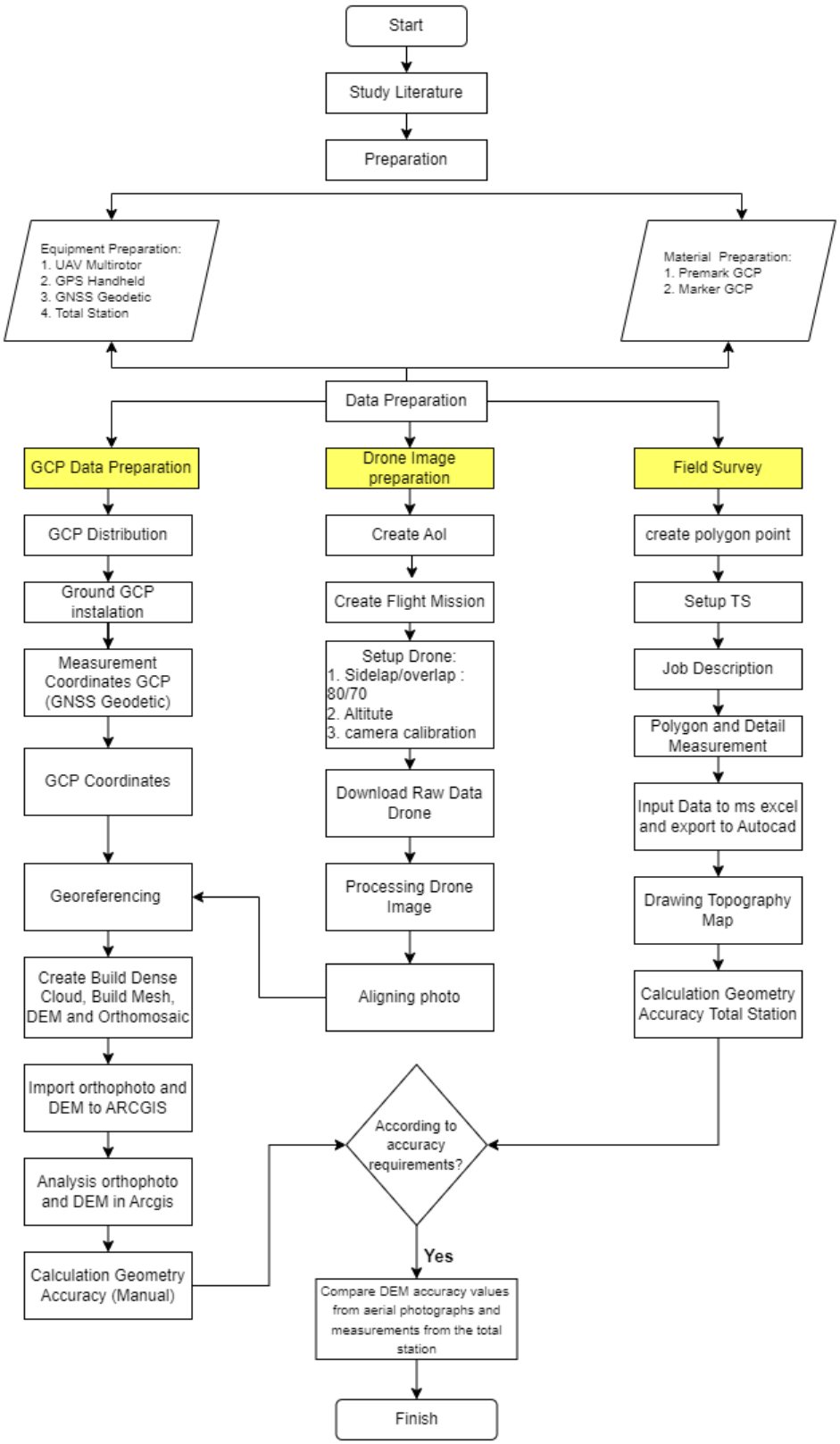


Figure 4 Research Methodology

3.1. Establishment of GCP and ICP

The GCP and ICP were established before the acquisition of aerial photographs. In the study area, 6 GCPs and 5 ICPs are installed on the ground. Each ground control marker measures 1.40 m x 1.40 m. The coordinates for GCPs and ICPs were calculated using the Trimble R8s Geodetic GNSS, employing the RTK-NTRIP method. This process referenced the BIG's fixed CORS station. The GCPs were positioned along the boundaries and at midpoints of the survey area (Udayanga et al., 2021). Figure 5 shows the GCP measurement activity.

Figure 5 GCP Measurement

3.2. Flight Planning and Image Acquistion

The flight path mission was designed using the Pix4D application. This process involved importing the Area of Interest (AoI), a previously defined study area, created using Google Earth Pro and saved in KML format. By utilizing specific information from the AoI, the Pix4D application was able to plan the optimal flight path (see Figure 6). The flight path planning employed the nadir method for aerial photography, which arranges the photography in a zig-zag pattern on a single-grid mission flight path. With a set flight altitude of 100 meters above ground level (AGL), medium speed, an overlap of 80%, and a vertical camera angle perpendicular to the Earth's surface, this method ensures optimal aerial photography.

(a) (b)

Figure 6 Flight Path Mission (a), Information Flight Path Single Grid Mission (b)

3.3. Terrestrial Measurement (Total Station)

After acquiring aerial photos, the next step is terrestrial measurements using the Total Station Focus 2 5". This measurement aims to obtain coordinate data (x, y, z) from previously determined points, namely the GCP and ICP points. The coordinate values (x, y, z) of BM1, obtained from Geodetic GNSS measurements, are first inputted. Following this, aiming is carried out toward the tribrach at BM2 to determine its coordinates. This process is followed by the detailed measurement of surrounding points, including the GCP and ICP points.

3.4. Processing Data

The data processing stage consists of several steps. First, aerial photography data and GCPs are processed using Agisoft Metashape Professional software, resulting in DEM and Orthophoto data. Second, the ICP data and Orthophoto are processed to correct the accuracy of the aerial photo data using ArcGIS software. Subsequently, Total Station data is processed using Microsoft Excel, and contour lines are drawn using AutoCAD Civil 3D software. The final step involves comparing the processed data from the aerial photos with the processed data from the Total Station.

3.4.1 Image Processing

The principal objective of this process is to generate a georeferenced 3D point cloud from overlapping aerial image data. This method, known as Structure from Motion (SfM), includes Dense Point Cloud, Digital Terrain Model, and Orthophoto (Figure 7), a technique fundamentally similar to stereoscopic photogrammetry. By leveraging image overlaps, SfM recreates a 3D structure of the object of interest. Various existing software, such as Agisoft PhotoScan, can generate this type of 3D point cloud (Polat & Uysal, 2017). The advancement of software in UAV applications has enabled the generation of orthophotos in a desired coordinate system. A powerful computer is recommended to utilize the software processing large amounts of data (Siebert & Teizer, 2014).

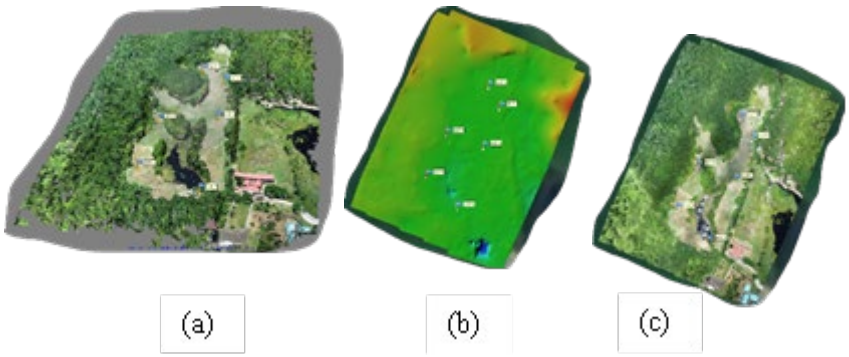


Figure 7 Dense Point Cloud (a), Digital Terrain Model (b), Orthophoto (c)

3.4.2 Import

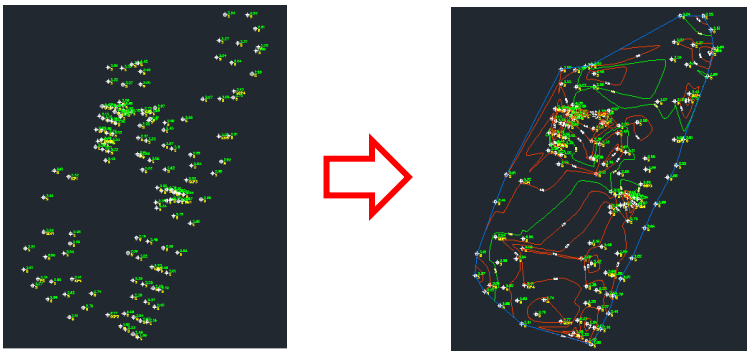
Orthophoto and DTM to ArcMap

The raster data of the Orthophoto and DTM, in conjunction with the coordinates of the ICPs, were analyzed using GIS software in a process known as overlay analysis. This intricate process allowed us to obtain precise geometric accuracy in horizontal and vertical dimensions. The overlay analysis facilitated the alignment of multiple geospatial datasets and enabled the

investigation of spatial relationships, interactions, and dynamics among the overlaid layers. This precise computation of the geometric accuracy of the spatial data derived from the orthophotos and DTM is crucial in assessing the fidelity and validity of the spatial datasets, thereby aiding in making informed decisions in numerous geospatial applications.

3.4.3 Total Station Processing

Autodesk Civil 3D was used to process coordinates obtained from terrestrial measurements using a Total Station (Nikolova, 2006). The primary objective of this processing phase was to generate a vector contour map. This software allows for the creation of sophisticated, high-resolution contour maps from the collected data. The contour maps provide crucial insights into the spatial distribution and characteristics of the terrain, helping to understand topographic variations more effectively. In this study, a total of 144 coordinate points dispersed throughout the study area, including Ground Control Points (GCPs), Independent Check Points (ICPs), and Benchmarks (BMs), were input into the Autodesk Civil 3D software. The coordinate points generated from the total station can be seen in Figure 8.



(a) (a)

Figure 8 Coordinates Point (a), Surface Contour (b)

4. RESULTS AND DISCUSSION

4.1. Horizontal Analysis Accuracy

The horizontal position accuracy test refers to the difference in coordinates (X, Y) between the ICP test points on the map (Orthophoto) and the actual ICP test points on the ground. Accuracy measurement uses Root Mean Square Error (RMSE), which describes accuracy by accounting for both random and systematic errors (Saputra et al., n.d.). This RMSE can be calculated once the coordinate transformation is completed. In this analysis, the data to be analyzed include the comparison between the ICP coordinate data from the Orthophoto, and the ICP coordinate data from the GNSS Geodetic, as well as the comparison between the ICP coordinate data from the Total Station and the ICP coordinate data from the GNSS Geodetic.

4.1.1 Analysis of Horizontal Accuracy of Orthophoto

The analysis of the orthophoto's horizontal accuracy reveals an RMSExy value of 0.3192 m, as shown in Table 3. The accuracy of the orthophoto coordinates is quantified by the CE90 value of 0.485 m, indicating a high level of horizontal accuracy. This value signifies that the orthophoto position error remains within the accuracy threshold with a 90% confidence level. Figure 9 shows the graph of difference in coordinate values between Horizontal Orthophoto and Geodetic GNSS.

Table 3 Horizontal Accuracy of Orthophoto

No.	Point Name	Coordinates (X) Orthophoto (m)	Coordinates (X) GNSS Geodetic (m)	(YX)	$(YX)^2$	DX^2+DY^2
1	ICP 1	180236.647	180236.496	-0.058	0.003	0.026
2	ICP 2	180312.396	180312.291	0.000	0.000	0.011
3	ICP 3	180341.962	180342.135	0.025	0.001	0.031
4	ICP 4	180252.454	180252.5	-0.177	0.031	0.033
5	ICP 5	180403.094	180403.207	0.629	0.396	0.408
				Total		0.510
				Average		0.102
				RMSEr		**0.3192**
				CE90		**0.4845**

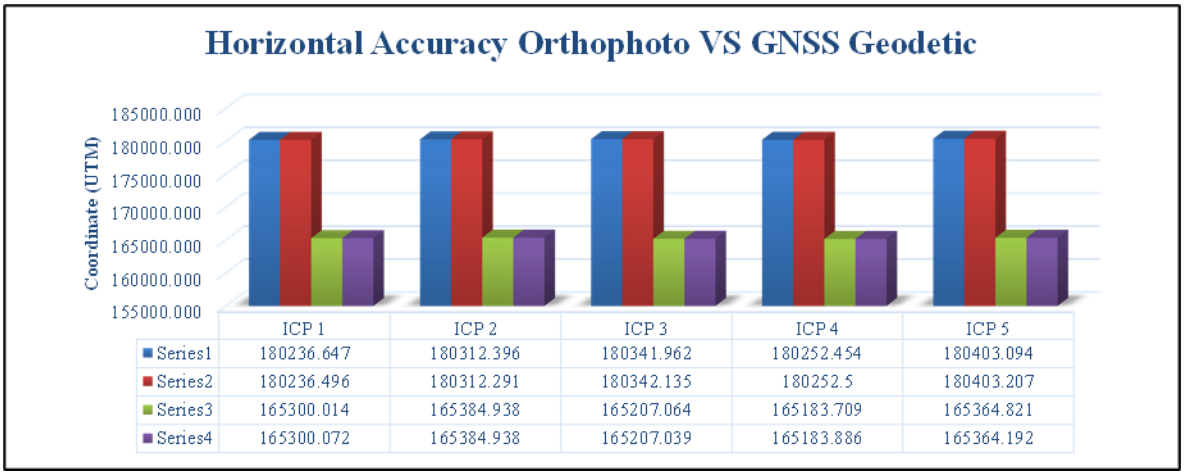


Figure 9 Graph of Difference in Coordinate Values between Horizontal Orthophoto and Geodetic GNSS

4.1.2 Analysis of Horizontal Accuracy of Total Station

The horizontal accuracy resulting from field measurements using a Total Station is in Table 4.

Table 4 Horizontal Accuracy of Total Station

No	Point Name	Coordinates (X) Orthophoto (m)	Coordinates (X) GNSS Geodetic (m)	(YX)	$(YX)^2$	DX^2+DY^2
1	ICP 1	180236.443	180236.496	-0.034	0.001	0.026
2	ICP 2	180312.253	180312.291	-0.030	0.001	0.011
3	ICP 3	180342.167	180342.135	0.056	0.003	0.031
4	ICP 4	180252.536	180252.5	0.040	0.002	0.033
5	ICP 5	180403.147	180403.207	-0.047	0.002	0.408
				Total		0.019
				Average		0.004
				RMSEr		**0.0619**
				CE90		**0.0940**

Based on Table 4, the RMSExy value is 0.0619 m. The Total Station coordinate accuracy value is represented by the CE90 (Circular Error) value of 0.094 m for horizontal accuracy. This means the Total Station coordinate point position error does not exceed the accuracy value with a 90%

confidence level. Figure 10 shows the graph of difference in coordinate values between Horizontal Total Station and Geodetic GNSS.

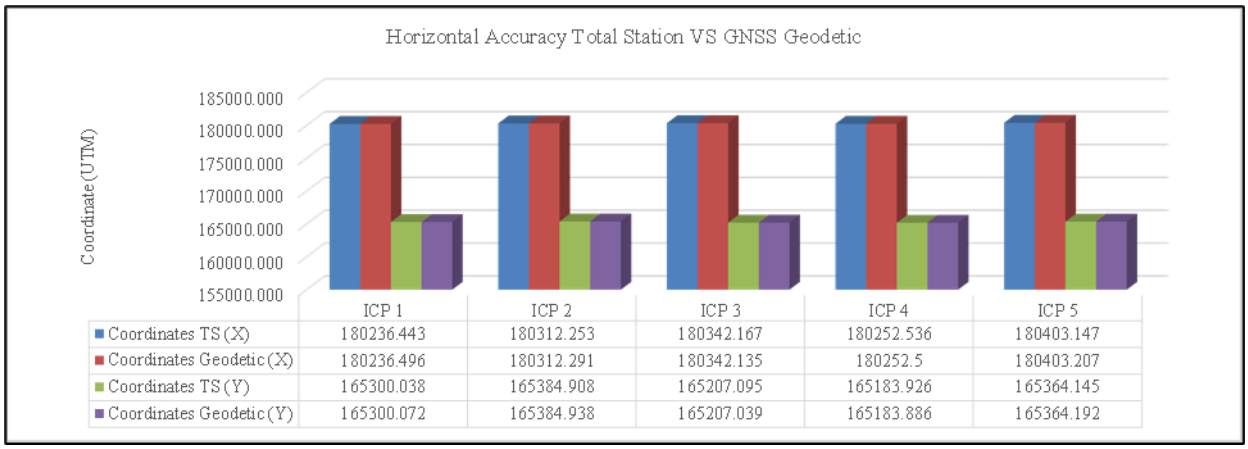


Figure 10 Graph of Difference in Coordinate Values between Total Station and Geodetic GNSS

4.2. Vertical Analysis Accuracy

The vertical position accuracy test refers to the difference in elevation (Z) between the map's ICP test points and the Geodetic's ICP points. Accuracy testing uses Root Mean Square Error (RMSE), which describes accuracy by accounting for random and systematic errors. This RMSE can be calculated once the elevation transformation is completed. In this analysis, the data to be analyzed includes the comparison between ICP elevation data from the DTM and ICP elevation data from GPS Geodetic, as well as the comparison between ICP elevation data from the Total Station and ICP elevation data from GPS Geodetic.

4.2.1 Analysis of Vertical Accuracy of Orthophoto

The DTM vertical accuracy calculation results generated from aerial photographs are shown in Table 5, in which the RMSEz value is 0.197 m. The DTM elevation accuracy value is represented by the LE90 (Linear Error) value of 0.325 m for vertical accuracy. This means that the error in the elevation value on the DEM does not exceed this accuracy value, with a 90% confidence level. Figure 11 shows the graph of difference in Elevation Values between DTM and Geodetic GNSS.

Table 5 Vertical Accuracy of Orthophoto

No	Point Name	Elevation DTM (m)	Elevation GNSS Geodetic (m)	(DX)	$(DX)^2$
1	ICP 1	3.436	3.557	-0.121	0.015
2	ICP 2	2.553	2.778	-0.225	0.051
3	ICP 3	2.521	2.633	-0.112	0.013
4	ICP 4	2.210	2.550	-0.340	0.116
5	ICP 5	2.882	2.887	-0.005	0.000
				Total	0.193
				Average	0.039
				RMSEr	0.197
				CE90	**0.325**

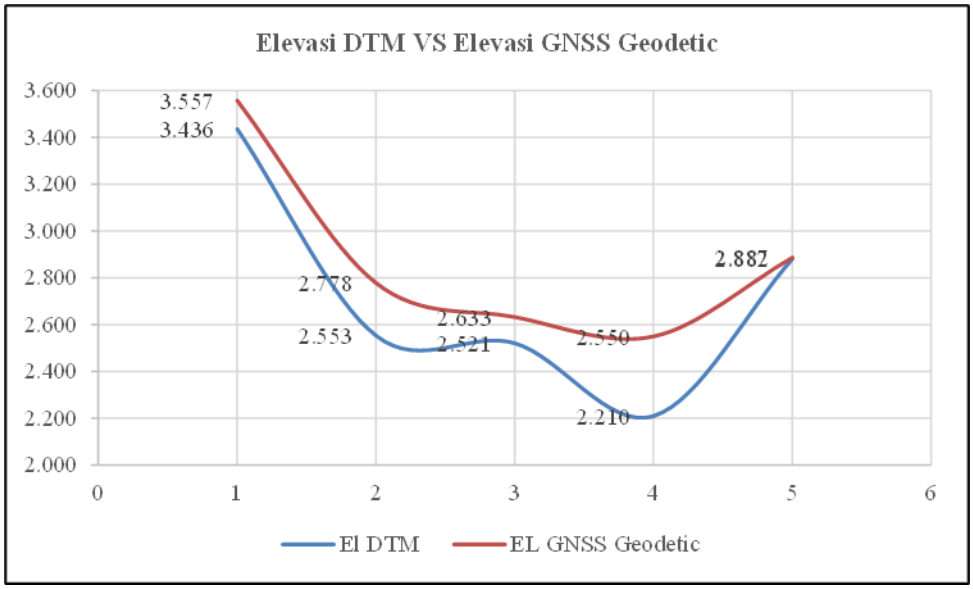


Figure 11 Graph of Difference in Elevation Values Between DTM and Geodetic GNSS

Based on Table 5, the RMSEz value is 0.197 m. The DTM elevation accuracy value is represented by the LE90 (Linear Error) value of 0.325 m for vertical accuracy. This means that the error in the elevation value on the DEM does not exceed this accuracy value, with a 90% confidence level.

4.2.2 Analysis of Vertical Accuracy of Total Station

The vertical accuracy values obtained from field measurements using a Total Station are presented in Table 6.

Table 6 Vertical Accuracy of Total Station

No	Point Name	Elevation Total Station (m)*	Elevation GNSS Geodetic (m)**	(DX)	$(DX)^2$
1	ICP 1	3.513	3.557	-0.044	0.002
2	ICP 2	2.749	2.778	-0.029	0.001
3	ICP 3	2.597	2.633	-0.036	0.001
4	ICP 4	2.495	2.550	-0.055	0.003
5	ICP 5	2.910	2.887	0.023	0.001
				Total	0.193
				Average	0.039
				RMSEr	0.197
				CE90	**0.325**

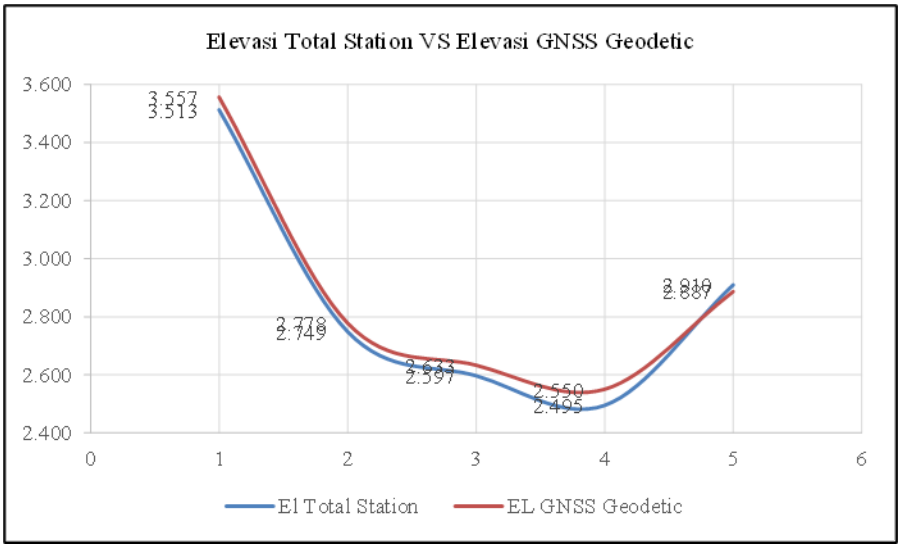


Figure 12 Graph of Difference in Elevation Values Between Total Station and Geodetic GNSS

4.3. Comparison of Data Accuracy

4.3.1 Comparison of Geometry Accuracy Value

Data accuracy from aerial photographs and terrestrial measurements using a Total Station is assessed through the Root Mean Square Error (RMSE) method. This method yields error data and determines the accuracy obtained from both approaches. A comparative analysis will be conducted to evaluate the significance of the error rate and ascertain the accuracy of the data derived from these two methods. The data accuracy comparison between aerial photographs and terrestrial measurements using a Total Station is presented in Table 7.

Table 7 Comparison of Accuracy between Orthophoto from UAV and Total Station Data

Method	RMSExy (m)	RMSEz (m)	CE90 (m)	LE90 (m)
Orthophoto	0.312	0.197	0.485	0.325
Total Station	0.062	0.039	0.094	0.064

4.3.2 Comparison of Elevation of Total Station and DTM

The presented cross-sections serve as a singular illustration for comparison purposes at a specific sampling location. Each software employed to create contour maps produces cross-sectional images. Based on Figure 13 and Figure 14, disparities arise between the elevation values derived from the DTM data and those obtained from measurements via a Total Station. As depicted in Figure 13, the DTM elevation value at the 25-meter station is recorded as 2.75 meters, whereas the elevation measured using the Total Station amounts to 2.7 meters. Similarly, at the 50-meter station, the DTM elevation is calculated as 2.58 meters, in contrast to the Total Station measurement of 2.60 meters. The ensuing cross-sectional images provide a comparative analysis of the DTM and Total Station data.

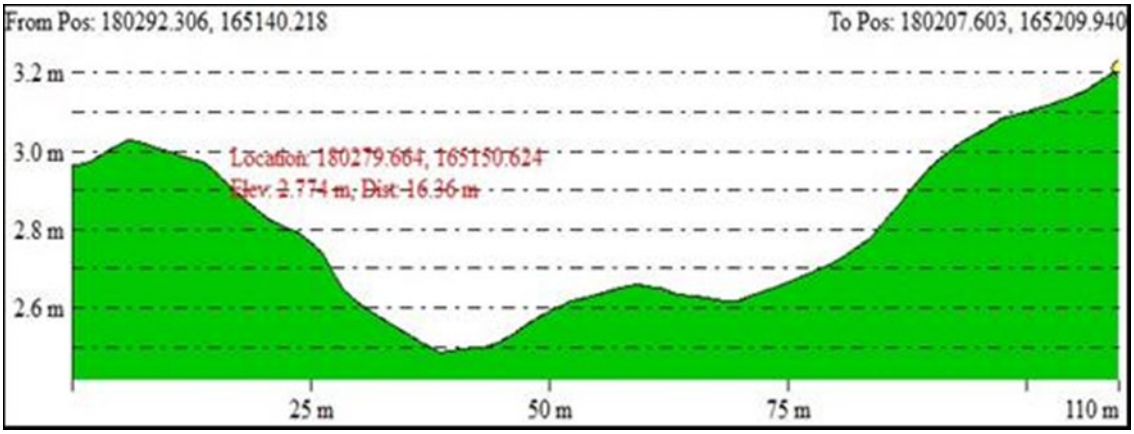


Figure 13 Cross Section on Contour Generated from DTM UAV

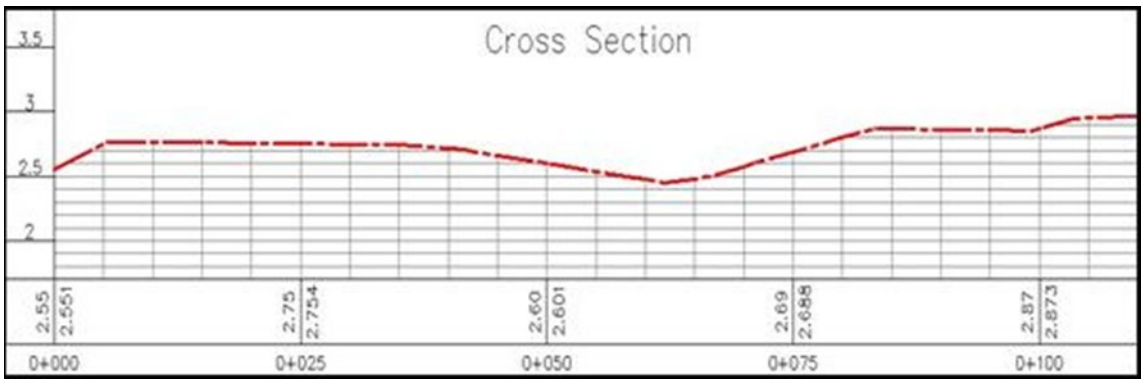


Figure 14 Cross Section on Contour Generated from Total Station

4.4. Basic Geometry Accuracy Analysis

The accuracy of the maps is based on the regulations of the Head of the BIG. Each map produced using aerial photo data has a map class accuracy value. The accuracy of the map class can be determined by calculating the values of CE90 and LE90, which represent horizontal and vertical accuracy, respectively. After selecting the values of CE90 and LE90, the map accuracy class can be categorized at a particular scale.

4.4.1 Geometry Accuracy of Aerial Photography

Table 8 Test Values of CE90 and LE90 Map Scale 1:1000 Aerial Photograph Data

Accuracy Test	Accuracy Test Result CE90 dan LE90	Scale Map Accuracy 1:1000		
		Grade 1	Grade 2	Grade 3
Horizontal	0.485	0.2	0.3	0.5
Vertical	0.325	0.2	0.3	0.5

It can be concluded from the Table 8 above that the results of the CE90 and LE90 tests are included in the map scale of 1:1000, with horizontal accuracy fulfilling class 3 and vertical accuracy also in class 3.

4.4.2 Total Station Geometry Accuracy

Table 9 Test Values of CE90 and LE90 Map Scale 1:1000 Total Station Data

Accuracy Test	Accuracy Test Result CE90 dan LE90	Scale Map Accuracy 1:1000		
		Grade 1	Grade 2	Grade 3
Horizontal	0.094	0.2	0.3	0.5
Vertical	0.064	0.2	0.3	0.5

It can be concluded from the Table 9 above that the results of the CE90 and LE90 tests are included in the map scale of 1:1000, with horizontal accuracy fulfilling class 1 and vertical accuracy also in class 1.

5. CONCLUSION

This research compares the precision and accuracy of DTM raster data from the DJI Phantom 4 Pro V.2 with elevation data from terrestrial measurements using a Total Station. The drone used is the DJI Phantom 4 Pro V.2, equipped with a 20-megapixel camera, and the study area covers 16.30 hectares. A total of 253 aerial photographs were captured 100 meters above the ground, resulting in a Ground Sampling Distance (GSD) resolution of 2.63 cm/pixel.

The SfM photogrammetric method obtained point clouds, digital surfaces, and orthophotos from aerial photographs. The results showed that the horizontal accuracy (x, y) of the Total Station is better than that of aerial photographs, indicated by the Total Station RMSE (xy) value of 0.062 m and CE value of 0.094 m, compared to the RMSE (xy) value of 0.319 m and CE value of 0.485 m for aerial photographs. The vertical accuracy results also show that measurements using a Total Station are more accurate than those using aerial photo data, with the Total Station RMSE(z) value at 0.039 m and LE90 (Linear Error) value at 0.064 m, compared to the RMSE(z) value of 0.197 m and LE90 value of 0.325 m for aerial photographs.

It can be concluded that the horizontal and vertical accuracy values obtained using the Total Station are superior to those obtained from aerial photographs. This disparity is attributed to several factors, including the limitation of the RGB camera sensor on drones, which cannot penetrate vegetation or hidden objects such as the ground. Therefore, further research on using LiDAR sensors is recommended (Lohar et al., 2021). Additionally, increasing the distribution of GCPs in the research area is advisable to enhance the quality and accuracy of aerial photographs.

The measurement method using GNSS Geodetic NTRIP-RTK does not provide the highest level of accuracy. Therefore, it is recommended to use the Static (Kinematic Post-Processing) method, which offers higher accuracy. With this method, Geodetic GNSS data can be used as a reference to achieve a high level of accuracy in calculating the root mean square error (RMSE).

This research makes a significant contribution to the geospatial science by comparing the accuracy of contour data obtained through photogrammetric surveys using drones with data obtained through terrestrial surveys using Total Stations. The main contributions of this research include evaluating the precision and reliability of DEM data obtained from UAVs compared to Total Station measurements. Furthermore, it analyzes the horizontal and vertical accuracy using the RMSE method. Finally, it discusses the practical applications of these findings in mapping, surveying, and environmental engineering, where accurate terrain representation is of utmost importance. Additionally, it highlights the rapid advances in measurement technology, particularly in photogrammetry, and assesses their accuracy and precision. This research is essential for professionals who require precise measurements of land and features.

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INCREASING LEAN MANUFACTURING PROJECT PERFORMANCE IN PUMP PRODUCTION: CRITICAL SUCCESS FACTORS

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ABSTRACT

Floods represent a significant global disaster, occurring more frequently and causing severe damage. The effective production of pumps is crucial in supporting flood infrastructure projects. Lean Manufacturing (LM) and Project Management (PM) approaches must be incorporated to improve pump production manufacturing. Therefore, this study aims to identify the critical success factors that enhance LM performance in pump production projects for flood management through surveys conducted among pump manufacturers, governmental bodies, and relevant stakeholders engaged in flood infrastructure projects. The study's results highlight the importance of understanding and analyzing project complexity, aligning pump design with project requirements, and mastering processes and technical aspects, including method compliance and continuous improvement within the Lean framework. Effective project management, emphasizing goal clarity, planning, and execution, is also crucial. The insights obtained from this study significantly contribute to understanding the critical considerations in pump production to support flood infrastructure projects.

Keywords: Pump production; Flood infrastructure project; Critical success factor; Project complexity; Technical project management

1. INTRODUCTION

Floods are a major worldwide catastrophe, with their occurrence rapidly rising and causing severe consequences. According to Lewis and Kelman (2009), floods frequently immobilize cities, cause fatalities, and temporarily relocate thousands of citizens. Floods are caused by three primary factors: natural, infrastructural, and societal. Macro-climate changes influence natural elements, increasing sea levels and water levels surpassing those of land surfaces. Infrastructural issues encompass the issues of the accessible infrastructure and the declining efficiency of the existing systems, diminishing their ability to manage flood control. Social aspects encompass the community's limited awareness of keeping channels clean (Sandink & Binns, 2021).

Constructing flood pumps is useful in decreasing flood risks and mitigating disasters. However, it is crucial to carefully consider the trade-off between security, social advantages, and expenses in flood management. An efficient approach to flood management is the implementation of flood control pumps. The need for pump manufacturers is influenced by the growth of industries and technological advancements, with a growing emphasis on optimizing pump performance to meet the requirements of different systems.

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Although this movement brings forward new opportunities, it also poses challenges in ensuring the proper application of state-of-the-art technology, such as implementing Whole Life Cost or Totex, that enhances system value, further achieving optimal outcomes (Wilson, 2016).

The pump manufacturing industry has a significant market in the water sector, which provides profitable prospects for companies to grow and expand (Zeneli, 2016). Therefore, pump manufacturers are prioritizing innovation and improving the manufacturability of their goods to meet changing demands. It involves improving the quality of a product or service while minimizing costs and the time it takes to complete a task. Therefore, industries must prioritize implementing continuous performance improvement approaches (Samanta et al., 2024).

Companies are motivated to achieve outstanding performance through market competitiveness, continuous improvement of organizational maturity, pursuit of corporate development, and strategies focused on enhancing the workforce for organizational excellence. Furthermore, they are also expected to reduce waste and preserve resources by environmental concerns (Kumar et al., 2022). Therefore, pump manufacturing must implement Lean Manufacturing (LM) and Project Management (PM) approaches to obtain those objectives.

Implementing PM principles reduces the haphazard application of tools, leading to discipline, organization, and a focus on achieving goals throughout the process. The strategic integration of LM and PM can result in a synergistic impact, significantly enhancing the efficiency of transformations. It is important to acknowledge that LM projects have characteristics that demand specific criteria for implementing PM techniques (Suetina et al., 2014).

Implementing LM methods in industrial companies should be approached as a project-oriented effort that involves many business units and organizational levels. Managers should get training in the core principles of PM, while all employees should understand the basic concepts of lean production to enable comprehensive integration. Even isolated lean production initiatives show potential for improving efficiency. Nevertheless, placing a higher priority on utilizing factors rather than on problem-solving can impede efficacy. The employees involved may lack knowledge and enthusiasm, and their inadequate expertise in PM can hinder the implementation process. Although there may be difficulties, well-implemented lean production projects can result in substantial advantages, such as improving operational efficiency (Belchik & Ezhov, 2021). This study aims to determine the key factors contributing to the success of LM in the pump production project, filling the gaps in present practices and offering insights to enhance pump production processes for future flood infrastructure projects by incorporating an LM approach.

2. LM AND PM IN PUMP PRODUCTION MANUFACTURING

2.1. Pump Production Manufacturing Factors

The increasing demand for personalized products has led to a rise in engineer-to-order (ETO) companies. The European Union (EU) is the largest producer and exporter of machinery globally, making the ETO industry a significant sector within the EU. ETO involves a customer-centric approach where each order initiates the engineering, fabrication, and on-site installation of products, often with high levels of customization. Customer involvement throughout the design and engineering phases adds complexity to PM. ETO industries manage various processes simultaneously, including engineering, procurement, and manufacturing, to meet tight deadlines and budget constraints. This paper refers to the term 'ETO industry' encompassing machinery and plant manufacturing with subsequent on-site assembly and construction suppliers performing final installations on-site (Schulze & Dallasega, 2023).

2.2. LM in PM

One approach to mitigate productivity losses involves implementing Lean methods. Originally developed in the automotive sector for highly repetitive production, Lean principles have gradually been applied across various manufacturing contexts. However, much of the existing literature on Lean focuses on product-centered, repetitive, and Make-to-Stock production scenarios, which involve consistent demand for large quantities of similar items. There is comparatively less empirical research on implementing Lean in non-repetitive settings and industries like ETO, which deal with low volumes and customized products. Adapting Lean to such environments presents significant challenges (Tomašević et al., 2021).

The implementation process often appears intimidating for many enterprises with new LM. Faced with challenges, many enterprises become dissatisfied with the concept and abandon further adoption (Samanta et al., 2024). Utilizing the project framework can serve as an efficiency multiplier in implementation, offering several benefits, such as streamlining the process, meeting deadlines, controlling costs, optimizing resource allocation, and engaging all personnel (Belchik & Ezhov, 2021).

This study explores the concept of 'Lean' and its significance for PM, specifically in the context of problem definition. Subsequently, the specific tasks for PM stemming from this principle are outlined. Subsequently, strategies for implementing these tasks are suggested as tools. Given that the effectiveness of tools is best demonstrated through application rather than in isolation, their presentation is intertwined with a continuous case study. This separates our approach from other management and PM resources, primarily focusing on procedures and fixed tools. In the 'Lean' framework proposed here, tools are viewed as suggestions that can be utilized, adjusted, and enhanced based on the unique demands of the situation, as long as they adhere to the underlying principles and fulfill the tasks at hand.

2.3. Key Factors of Integrating LM and PM in Pump Production Manufacturing

Using a production control framework that suits the characteristics of ETO manufacturing is crucial (Kingsman et al., 1993). In a Build-to-Order (BTO) environment, a well-designed model for product, process, and supply chain configuration can create a competitive advantage. The design and manufacture of complex ETO products can be enhanced using scheduling methods, which emphasize the value of visibility and planning in such environments (Schulze & Dallasega, 2023), which emphasize the value of visibility and planning in such environments (Schulze & Dallasega, 2023).

On the other hand, implementing PM involves integrating LM tools into industrial enterprises to achieve cost-effectiveness and various competitive advantages. Despite their complementary nature, PM and Lean differ in their fundamental components. Analyzing these distinctions will formulate a comprehensive perspective on implementing LM projects (Suetina et al., 2014). Table 1 outlines the key factors in LM and PM and their corresponding indicators.

Table 1 Factors of Implementations Project Management and Lean Management

Variable	Sub Variable	References
Variable X Critical Success Factors	Complexity; Human; Organizational; Process and Technical; Project Managementl Quality; Top Management	Adzmi & Hassan, 2018; Samanta et al. 2024 Gunduz & Mohammed, 2020
Variable Y Lean Management	Waste; Safety	Atkinson, 1999; Albanese, 1994; Lim & Mohamed, 1999; Womack & Jones, 1996

2.4. Development of Hypotheses

Building resilient models, such as Partial Least Squares Structural Equation Modeling (PLS-SEM), relies on well-crafted hypotheses (H). In examining the performance of pump manufacturing and understanding the relationships between key factors, hypotheses were meticulously developed based on existing literature and theoretical perspectives. This approach ensures that the model accurately captures the dynamics of LM and PM in pump production, providing valuable insights into optimizing these processes for enhanced performance and efficiency. Figure 1 shows the hypotheses development for this study.

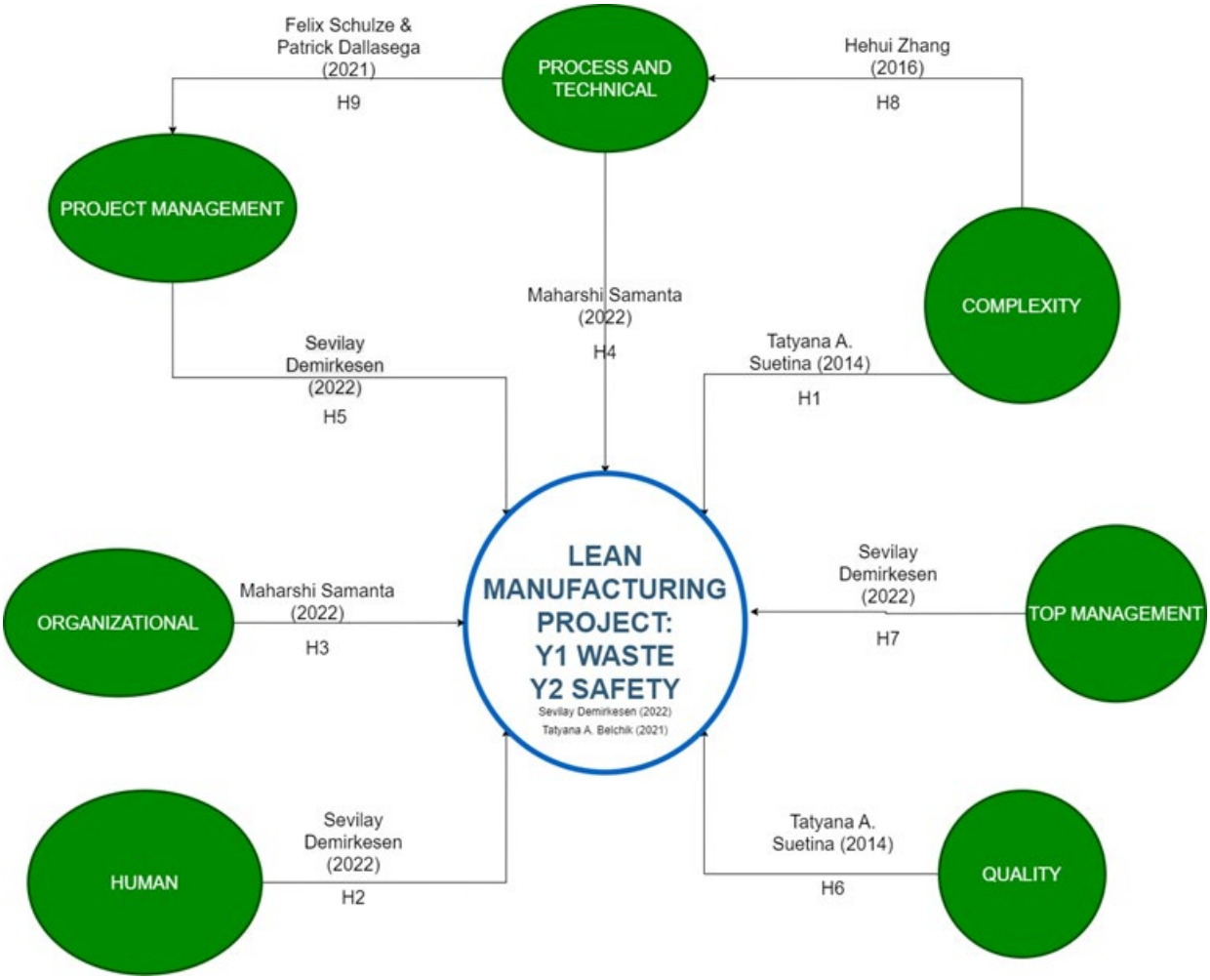

Figure 1 Development of Hypothesis

Two distinct parameters were defined to assess LM and PM integration: waste (Y1) and safety (Y2). These parameters address procedural aspects to improve customer satisfaction and project performance. The following hypotheses were formulated to explore the relationships between key factors and their impact on the Lean Manufacturing Project.

- H1: Complexity (X_1) positively affected the Lean Manufacturing Project (Y)
- H2: Human (X_2) positively affected the Lean Manufacturing Project (Y)
- H3: Organizational (X_3) positively affected the Lean Manufacturing Project (Y)
- H4: Process and Technical (X_4) positively affected Lean Manufacturing Project (Y)
- H5: Project Management (X_5) positively affected the Lean Manufacturing Project (Y)
- H6: Quality (X_6) positively affected the Lean Manufacturing Project (Y)
- H7: Top Management (X_7) positively affected Lean Manufacturing Project (Y)
- H8: Complexity (X_1) positively affected Process and Technical (X_4)
- H2: Process and Technical (X_4) positively affected Project Management (X_5)

3. METHODS

This research primarily adopted a quantitative method, combining survey questionnaire data with qualitative insights from industry experts to comprehensively analyze factors influencing pump production. The validity and reliability process was enhanced by triangulating the results. The research design used PLS-SEM to resolve complex relationships among latent constructs and capture non-linear patterns. This synergistic method improved the accuracy of the research, enabling credible assumptions and recommendations for implementing LM and PM in pump manufacturing.

3.1. Research Method

Before disseminating the questionnaire to construction workers, a validation process was carefully conducted by soliciting feedback from experts in the field. Their feedback was used to refine and validate the questionnaire surveys by revising, adding, or reducing factors. Expert 1 (E1), a Managing Director, emphasized the importance of achieving lean thinking by concentrating on tasks that add real value for the customers to ensure that every action taken during production contributes to customer satisfaction and overall efficiency. E2, a General Manager, recommended optimizing lead time to enhance the added value. By reducing the time taken to complete each step of the production process, the overall value delivered to the customer can be significantly increased.

Furthermore, E3, a General Manager, advised implementing Value Stream Mapping for every step of the process to help visualize the flow of materials and information, identify bottlenecks, and highlight areas where improvements can be made. E4, a Business Development Manager, proposed identifying waste within the production process to reduce or eliminate it. Reducing waste makes the production process more efficient, cost-effective, and aligned with lean principles. E5 (Production Engineer) suggested conducting an Activity Analysis to evaluate waste and added value tasks. This analysis helps distinguish between necessary and non-essential activities, ensuring efforts are concentrated on value-adding tasks.

Each variable selected from the literature and carefully vetted by experts to ensure validity and relevance was then used as items to be asked in the questionnaire survey. The validated variables from the expert validation were then prepared as the items asked in the questionnaire survey (see Table 2). The questionnaire survey comprises two sections, began with instructions, research

objectives, and inquiries concerning the demographics of respondents. The subsequent section examined the factors influencing pump production related to flood control projects, explaining each factor using multiple items.

Table 2 Variables and Indicators in Influencing Pump Production

Code	Aspects	Code	Indicators	Decision	Reason
X1	Complexity	X1.1	Understanding and analysis of comprehensive project complexity	Keep	
		X1.2	Strategy management for project complexity	Eliminate	Included in X1.1
		X1.3	Flexibility and adaptability to change	Eliminate	Included in X1.5
		X1.4	Clear communication and alignment of the project's objective with stakeholder	Eliminate	Included in X1.1
		X1.5	solid risk management for reducing complexity	Keep	
X2	Human	X2.1	Member competent team	Eliminate	Included in Organizational Qualification
		X2.2	There is training and certification	Eliminate	
		X2.3	Effective leadership	Eliminate	
X3	Organizational	X3.1	Culture organization	Keep	
		X3.2	Structure clear organization	Keep	
X4	Process and Technical	X4.1	Methodology management clear project	Keep	
		X4.2	Access to tools and applications management suitable project	Keep	
		X4.3	Application engineering and expertise-proven technical	Eliminate	Included in X4.4
		X4.4	Obedience to standards and regulations in the industry	Keep	
		X4.5	Procedure management clear changes	Keep	
		X4.6	Recording Continuous improvement and lessons learned	Keep	
X5	Project Management	X5.1	Planning and scheduling effective project	Keep	
		X5.2	Clear definition of room scope, objectives, and results of projects	Keep	
		X5.3	Allocation and management source efficient power	Eliminate	Included in X5.6
		X5.4	Management risks and strategies strong mitigation	Keep	
		X5.5	Proper communication and coordination time between member team project	Keep	
		X5.6	Monitoring and controlling the progress of the project to the bottom line set	Keep	
X6	Quality	X6.1	Standards and metrics specify quality	Keep	
		X6.2	Implementation of assurance processes quality and control quality	Keep	
		X6.3	Monitoring and evaluation results of sustainable project	Keep	
		X6.4	Mechanism bait comes back for increased quality throughout the life cycle project	Eliminate	Included in X6.3
		X6.5	Prevention disabled, not only detection and correction	Keep	

Code	Aspects	Code	Indicators	Decision	Reason
X7	Top Management	X7.1	Clear commitment to successful project	Keep	
		X7.2	Removal of obstacles to the organization	Eliminate	Included in X6.3
		X7.3	Alignment strategy with objective organization	Eliminate	
		X7.4	Making decisions and solutions to the right problem at the time	Keep	
		X7.5	Effective communication about priorities and goals project to stakeholder interest	Keep	
Y1	Waste	Y1.1	Overproduction	Eliminate	Not related to the ETO project
		Y1.2	Waiting Time	Keep	
		Y1.3	Transportation	Keep	
		Y1.4	Over Processing	Keep	
		Y1.5	Inventory	Keep	
		Y1.6	Unnecessary Motion	Keep	
		Y1.7	Defects	Keep	
Y2	Safety Work	Y2.1	There is no accident work	Eliminate	Lean linked to value creation

The questionnaire was designed using a five-point Likert scale, ranging from one (completely disagree) to five (completely agree). The target respondents were construction workers affiliated with consultants or contractors directly or indirectly involved in bridge maintenance projects. To ensure data adequacy, a minimum number of respondents was validated using Equation 1 (Sun & Wang, 2009):

$$N' = \left(\frac{\frac{k}{s}\sqrt{N\sum x^2 - (\sum x)^2}}{\sum x}\right)^2 \qquad (1)$$

The methods used in this research progressed through distinct stages, as illustrated in Figure 2.

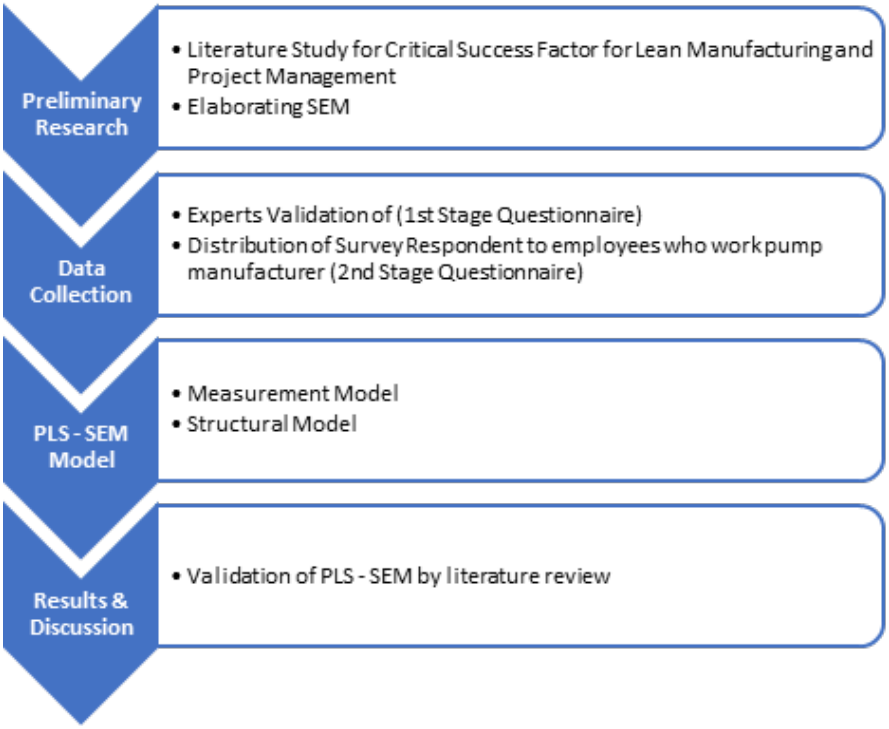

Figure 2 Research Flow

The methods progressed systematically, starting with a thorough literature review to identify the factors affecting Lean Manufacture Project Performance in the Indonesian or Pupm manufacturing industry. Therefore, a carefully designed survey questionnaire was distributed to respected industry practitioners and subject matter experts to obtain valuable insights.

3.2. Data Analysis Method

The gathered dataset was subjected to thorough analysis using PLS-SEM with the aid of the SMARTPLS software. PLS-SEM was selected because it effectively resolved complex relationships among latent variables. Additionally, it is highly versatile, accommodating reflective and formative constructs, and requires smaller sample sizes than traditional SEM methods. The parameters that regulate the PLS-SEM analysis were carefully adjusted to ensure accuracy. The number of iterations was 65, and the convergence criterion was established at an impressive threshold of 1.0E-7 (49). These adjustments were carefully made to ensure the convergence and stability of the model, thereby improving the reliability and robustness of the analysis.

4. RESULTS AND DISCUSSION

4.1. Result

Several preliminary statistical tests were conducted before modeling to ensure the suitability of the data for multivariate analysis. Assessing the reliability of the questionnaire and normality assumption was crucial, requiring a normal distribution evaluation. The reliability and normality of the data were tested using Cronbach's alpha and the Shapiro-Wilk test. The results indicated that the data were reliable, with a Cronbach's alpha of 0.845 ($p > 0.5$), but not normally distributed ($p < 0.05$). From these results summarized in Table 3, we can conclude that the test should be non-parametric.

Table 3 Normal Distribution Test

Parameter	Saphiro-Wilk	
	Test-Statistic	Exact Sig.
Complexity (X_1)	0.750	0.000
Organizational (X_3)	0.694	0.000
Process and Technical (X_4)	0.769	0.000
Project Management (X_5)	0.633	0.000
Quality (X_6)	0.710	0.002
Top Management (X_7)	0.717	0.000
Lean Manufacture (Y_1)	0.118	0.000

After confirming the reliability and validity of the measurement model, a structural framework was constructed to evaluate the basic relationships among factors in the hypothetical model. Due to the non-normal distribution, PLS-SEM was favored over covariance-based SEM for handling such distributions (Leong, 2019). Smart PLS 4 was used to validate the assumptions of the proposed model, the result of which is shown in Figure 3.

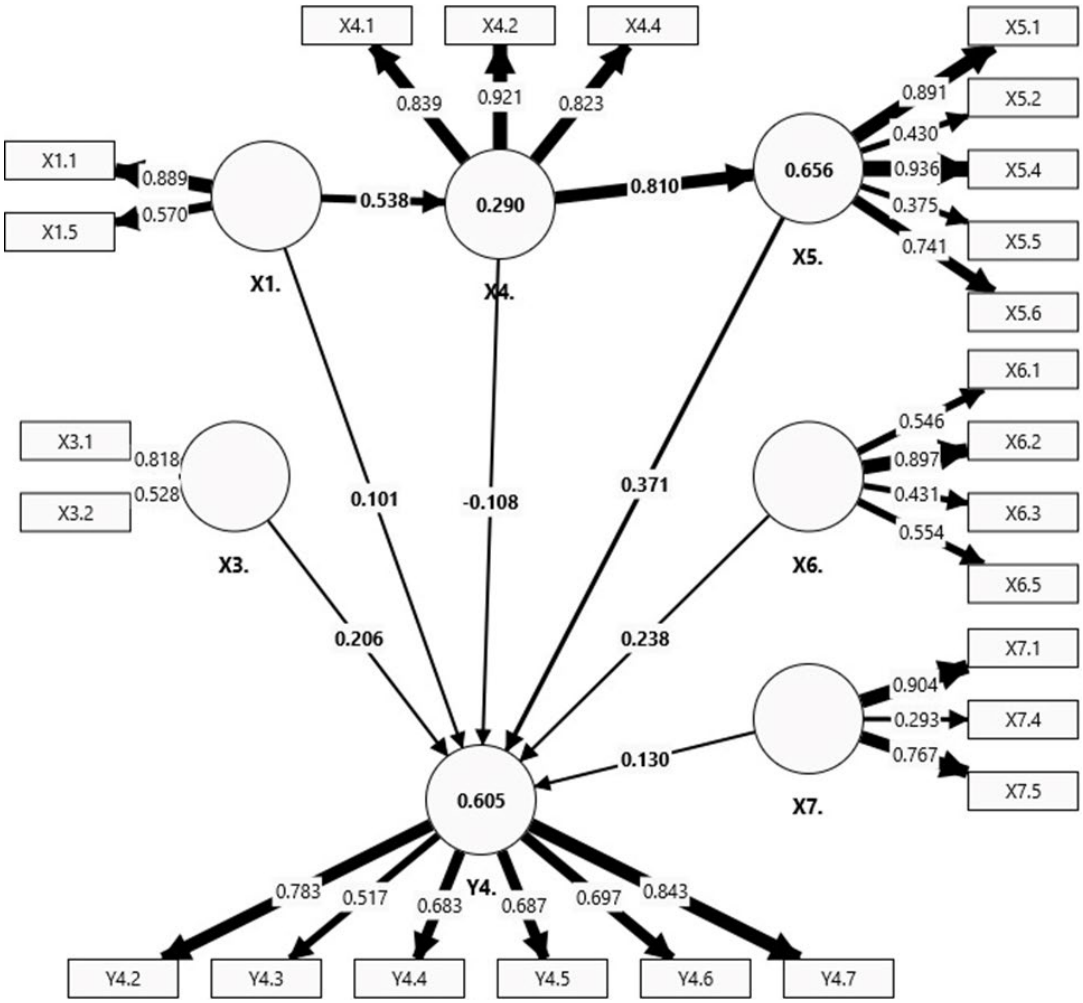

Figure 3 Result from SMART PLS-4

The R-squared, or coefficient of determination, result was 0.618, indicating the proportion of the dependent variable's variation that can be predicted from the independent variable. The result shows that the independent variable can predict 61% of the variation in the dependent variable (see Table 4).

Table 4 Composite Reliability and AVE

Variable	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Complexity	0,292	0,702	0,556
Organizational	-0,128	0,633	0,474
Process and Technical	0,910	0,894	0,739
Project Management	0,859	0,815	0,502
Quality	0,590	0,710	0,399
Top Management	0,559	0,719	0,497
Lean Manufacture	0,820	0,856	0,502

Various tests were conducted to assess the structural–measurement model, including internal reliability, convergent validity, and discriminant validity criteria. Measures such as Dijkstra–Henseler's rho were used to determine construct reliability. Convergent validity was evaluated through item loadings, composite reliability, and Average Variance Extracted (AVE) values. Similarly, discriminant validity was examined by assessing correlations between potentially confounding variables. As shown in Table 5, only three variables had composite reliability and Rho-A values exceeding 0.50, depicting robust construct reliability. AVE values greater than 0.50 supported the convergence of items to respective factors, thereby confirming factor validity. AVE values below 0.50 were eliminated.

4.2. Discussion

A key factor for engineers is translating customer requirements into specific quantitative specifications. Designers should also participate in commercial meetings with customers to discuss technical, commercial, and pricing details, ultimately leading to contract finalization. Considering design modifications are common before the design validation stage, opting for a fluctuating price contract is advisable to mitigate the risk of cost overruns in the ongoing project. Furthermore, specific parts' special material and process requirements should be outlined to facilitate early machining and purchasing (Zhang et al., 2016).

For many businesses newly introduced to LM, the implementation process often appears intimidating. Faced with these challenges, many enterprises become disillusioned and choose not to proceed with adoption. Utilizing the project framework is expected to enhance implementation efficiency, offering several benefits, including streamlining the process, ensuring adherence to deadlines and budget constraints, optimizing resource allocation, and involving all personnel in the enterprise.

The company where the research was conducted showed that complexity, process and technical mastery, and PM positively and consistently affect lean management. Mastery of complexity indicates a good analytical approach to project complexity, good management strategy, risk mitigation, and effective communication and alignment of goals among stakeholders (Adzmi & Hassan, 2018). Process and technical mastery indicate sufficient methods and tools to manage projects, adherence to procedures (Masrom et al., 2015), and continuous improvement (Gunduz & Almuajebh, 2020). A good PM is indicated by clear goals, expected results, and well-planned

steps for project execution (Masrom et al., 2015). Positive results show greater mastery of complexity, process, and technical aspects, and PM leads to more effective Lean PM.

A good PM can be useful at all stages of transformation within an enterprise, aided by LM tools. Utilizing PM reduces uncertainty in tool introduction and encourages discipline, organization, and goal alignment. A competent combination of PM and LM can create a synergistic effect, significantly increasing renovation effectiveness. However, LM projects have certain peculiarities that impose special requirements on PM methods.

5. CONCLUSION

Successfully incorporating LM relies on integrating PM methods. Designers play a crucial role in interpreting consumer needs and reaching agreements through business negotiations to finalize contracts. Contracts with fluctuating prices allow for design revisions, while early identification of material and process requirements simplifies implementation. Findings indicate that the key factors for success in lean management are a comprehensive understanding and control of complexity, proficiency in managing processes and technical components, and effective project management. To effectively manage complexity, it is essential to have well-defined objectives, effective risk management, and alignment with stakeholders. Process and technical expertise are crucial, including strict adherence to methods and ongoing improvement. Efficient project management, with a focus on clearly defining objectives, strategic planning, and successful implementation, is essential. Integrating lean principles with strong project management methods simplifies transformations, improves performance, and generates synergistic impacts. Acknowledging the different requirements of lean projects and establishing a well-balanced management accounting system is crucial. An integrated approach emphasizing disciplined processes, orderliness, and goal focus greatly enhances organizational effectiveness.

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STRATEGIES FOR RESILIENT BUILD BACK IN THE POST-FLOOD ERA: AN AHP-DEMATEL TECHNIQUE

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ABSTRACT

Pakistan suffered from devastating floods in 2022, causing extensive infrastructural, economic, social, and other damages. Effective risk management was notably absent in the country. Therefore, this paper identifies critical factors influencing the build-back-better (BBB) framework and resilience building. The evaluation of various strategies for risk reduction in infrastructure during floods, ensuring its resilience, is also addressed. This study employs Multi-Criteria Decision Making (MCDM) techniques, specifically the Analytic Hierarchy Process (AHP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL), to assess critical factors in BBB in the context of devastating floods. The AHP analysis effectively ranked the identified factors based on their relative weights, while DEMATEL determined the inter-relationships among the parameters, categorizing them into effect and cause groups. The results indicate that improvement in structural design is essential, whereas asset replacement is the least important factor. According to the DEMATEL analysis, Cash-for-Work was the most important causal factor in improving resilience-building procedures. The findings of this study assist policymakers in formulating a risk-resilient framework for enhancing construction strategies and developing a strong and resilient infrastructure, effectively influencing associated stakeholders.

Keywords: AHP; Build-back-better; DEMATEL; Floods; Pakistan

1. INTRODUCTION

In 2022, Pakistan experienced one of the most severe floods in its history. Floods are considered the most consistently occurring and damaging natural hazard in Pakistan. Among all natural disasters affecting the population, 90% are due to floods (Papadonikolaki et al., 2022). The recent floods resulted in significant damage, with many people losing their lives and financial damages reaching billions (Bhamani, 2022). Official statistics reported that the floods caused the deaths of more than 1061 people and inflicted economic hardships, with more than 1,600 people injured (Bhamani, 2022). The most affected regions were Baluchistan, Sindh, Gilgit-Baltistan, Punjab, Azad Jammu Kashmir, and the Khyber Pakhtunkhwa (KPK) provinces. Pakistan's ability to implement changes to its systems and policies concerning disaster planning and management in response to climate change is weak (Uddin et al., 2013). This inadequacy has been a significant factor contributing to the severity of the floods. Countless people have been left homeless following these unprecedented rains and monsoon floods in Pakistan (Willner et al., 2018).

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The main issue contributing to Pakistan's frequent flooding every one or two years is mismanagement and a lack of awareness regarding precautionary measures to mitigate this disaster (Bukhari & Rizvi, 2010). Flash flooding caused by heavy rainfall has particularly devastated rural areas and green villages. Poor construction practices in flood-prone areas, insufficient investment in infrastructure, and inadequate precautions have been identified as the main causes of floods in the country. Pakistan is not resilient to floods, earthquakes, and other natural disasters (Bukhari & Rizvi, 2017). The country's lack of investment in climate-resilient infrastructure, coupled with mismanagement, climate change, and weak construction practices, exacerbates the problem (De, 2012; Kamran et al., 2022; Looney, 2016; Magsi et al., 2019). Much of the damage caused by the floods is due to structures that should not have been built, such as large hotels and communities along rivers. Poor elevations or low-lying areas have also been significant in flood damage, as floodwaters easily inundate and destroy buildings (Ahmed et al., 2014; Kronstadt, 2010).

This paper aims to identify the factors and strategies to bridge the gap between this calamity and providing a better-built environment. It is essential to locate the construction-related causes to prevent future hazards like these floods. Strengthening the country's recovery phase is crucial so that future flood impacts are less severe. The main objectives of this study are to (1) determine the construction-related causes of the 2022 flood; (2) to present suggestions for better build-back and resilience building in the post-disaster recovery of the 2022 floods in Pakistan; and (3) to understand the influence of earlier decisions on building back better for the re-establishment and long-term recovery of communities affected by the 2022 floods in Pakistan.

Collaboration on technical assistance to improve systems, infrastructure, and more resilient construction practices must be ensured to mitigate future flood disasters (Pradhan et al., 2022). Studying and identifying factors that can lessen the impact of floods is crucial, as floods damage agriculture and property and endanger human lives, which are the most valuable (Sarkar, 2022). Floods are the most frequent natural hazards that bring significant economic losses and difficulties (Ahmad & Afzal, 2022). This paper attempts to be a valuable resource for addressing issues related to flood disasters in the future. Previous studies have provided detailed literature on other natural disasters, such as earthquakes and landslides, but the most damaging disaster in terms of psychological, economic, and infrastructural impact on communities is flooding (Ahmed, 2022; Farooq & Fatima, 2022; Javed, 2021). The destruction caused by floods must be taken seriously, especially in rural areas of Pakistan, such as Khyber Pakhtunkhwa, where proper aid to combat these hazards is lacking (Ashraf Hussain et al., 2022; Zada et al., 2022). This paper proposes resilient strategies for a better-built environment, providing a pathway for future regulatory bodies, municipal authorities, and engineers to cope with these uncontrollable floods.

2. LITERATURE REVIEW

2.1. Build-back-better

Past studies on resilient build-back have been conducted by many researchers over the years (Meacham & McNamee, 2023). The build-back-better (BBB) approach proposes renovating and enhancing damaged infrastructure to endure future hazards more effectively (Der Sarkissian et al., 2021). The adaptive capacity of urban systems and their flood defences is crucial in addressing the challenges posed by climate change (Hofmann, 2022). If resilience is estimated and adopted carefully, it can significantly reduce the severity of flood damage.

Su et al. (2022) explained that construction improvements, particularly focusing on dam construction, can be a major factor in resilience to heavy floods. In Pakistan, dams help regulate water flow by storing water in reservoirs, reducing the probability of downstream flooding. Shahzad and Amjad (2022) highlighted that certain risks provoke flood disruption and that

management in Pakistan is not efficient or capable of mitigating these risks. This inefficiency is mainly due to poor management and inadequate forecasting to develop long-term strategies for building resilient infrastructure capable of withstanding heavy floods in Pakistan (Akbar et al., 2022; Shah et al., 2022). According to Mahmood et al. (2021), the unbearable damages caused by the 2022 floods require proper attention and detailed focus to formulate guidelines or pathways that authorities can consider in the future to reduce the impact of heavy floods.

2.2. Prominent Cause of Floods

Flooding is often caused by failing to track hazards and estimate potential damages. Sarkar (2022) explained that a combination of factors contributes to flooding in Pakistan. Shahid and Venturi (2022) identified climate change, corruption, and mismanagement as primary factors causing these floods to affect areas adversely. Sanderson et al. (2021) highlighted that increased corruption while constructing crucial infrastructure elements is a significant reason for flooding. It is largely accurate, as budgets approved for construction are not fully utilized due to corruption. Vaughan (2022) explained that using cheap materials in building construction leads to structures collapsing when floodwaters strike. The lack of dam construction or adequate water storage systems is another prominent cause of flooding, as Hussain et al. (2022) explained. This statement was further supported by Sami et al. (2022), who noted that in 2022, Pakistan experienced one of the worst disasters in the world when one-third of the country was underwater.

2.3. Strategies for Formulation of a Post-Flood Resilient Build-Back Environment

A comprehensive set of strategies is proposed in this section for the formulation of a post-flood resilient build-back environment, including long-term funding, new technologies, better land-use planning, functional partnerships between organizations, government support, educating communities, information centres establishment, asset replacement, cash-for-work, improvement in structural design, and post-disaster legislations.

1. Long-term Funding

Flood disasters have created significant economic severity and losses. Long-term financing must be managed to prevent economic damages caused by floods and other natural hazards (Mehring et al., 2022). Long-term funding must be available to cover the additional costs, as structural improvements are extremely costly and not affordable, particularly in post-disaster settings (Anwar, 2010; Ojo & Amassoma, 2021). Reconstruction quality can also be improved and maintained through proper inspection during reconstruction by local government authorities (Loudyi et al., 2022).

2. New Technologies

For future risk reduction, the incorporation and widespread installation of innovative, advanced, and novel technologies must be ensured (Pouryari, 2022). The conventional methods and technologies suggested by Papadonikolaki et al. (2022) must be replaced with new, innovative ones to improve infrastructures and mitigate damage. In 2000, India's efforts to replace existing processes with advanced technologies greatly reduced the impact of natural disasters (Islam et al., 2022).

3. Better Land-use Planning

A better land-use planning strategy was applied in post-disaster recovery efforts following the Indian Ocean Tsunami, leading to the rearrangement of coastal communities to mitigate future

coastal hazards (Stoker et al., 2022). However, well-envisioned land-use planning can fail due to a lack of awareness, knowledge, and information among residents and local authorities who do not enforce new regulations (Castro & Lechthaler, 2022).

4. Functional Partnerships Between Organizations

Functional partnerships and connections between organizations can enhance reconstruction projects (Nofal & Van De Lindt, 2022). Post-disaster recovery in a unique environment requires deviations from conventional processes, such as knowledge sharing between organizations. The Federal Emergency Management Agency (FEMA) in the United States supports information sharing, contacts, resources, and technical information to assist recovery activities. Information on previous hazards should be preserved and shared with the government and related organizations involved in future post-disaster efforts (Maiwald & Schwarz, 2022).

5. Government Support

The main responsibility of any government is to prioritize the community's needs, wants, and overall well-being over personal interests (Abd Razak et al., 2022). Disasters test the government's commitment to its citizens. Government support is vital for economic growth and safeguarding people from disasters like floods. The reconstruction phase requires government support to allocate budgets for public welfare. Government investment and assistance are crucial for building back better and ensuring a prosperous reconstructed environment (Marlow et al., 2022).

6. Educating Communities

Encouraging community education about risks and risk reduction measures is essential. Engaging communities in collective risk-reduction efforts is beneficial (Kamarudin et al., 2022). The Participatory Flood Risk Communication Support System (PAFRICS) developed in Japan aims to educate residents and stakeholders, including NGOs and local administrations, about flood risks and management strategies (Taki, 2022).

7. Information Centres Establishment

The development of information centers providing convenient access to recovery-related knowledge for the community is suggested by Yap et al. (2022). Maintaining a sense of public spirit and promoting communal consistency through group activities is recommended for social recovery (Sawangnate et al., 2022).

8. Asset Replacement

Asset replacement is essential from an economic perspective, ensuring the provision of crucial assets to industries that lost them due to the disaster. Training programs to increase skills among people are necessary so they can find jobs and earn a suitable livelihood (Figueiredo et al., 2021).

9. Cash-for-Work

Post-disaster recovery efforts include economic recovery policies such as "cash-for-work" programs and business grants. These programs address unemployment, lack of business, and income loss following disasters (Munawar et al., 2021).

10. Improvement in Structural Design

Risk reduction can be achieved through improved structural designs and better land-use planning. It requires updating building codes and land-use strategies, supported by a strong legal framework

and financial backing to encourage compliance (Zhang, 2021). Quality assurance in restructuring is also important for building back better after a disaster (Nguyen et al., 2021).

11. Post-disaster Legislations

Effective reconstruction and recovery require managing stakeholders and utilizing post-disaster regulations and legislation. Formulating a recovery authority to manage stakeholders and allocate resources is suggested. Positive recovery requires local partnerships and participation to ensure feasible solutions (Mannakkara, 2021). Implementing BBB-based concepts during recovery phases requires adequate post-disaster legislation to reduce risks and promote community recovery initiatives (Ocal, 2021).

2.4. Theme Identification

Strategies to build back better were identified by reviewing extensive literature and expert opinions. For this study, experts from various fields, including engineers, policymakers, and disaster risk reduction (DRR) experts in Pakistan, were selected. Through the literature review and expert opinions, 11 strategies were determined, as shown in Figure 1.

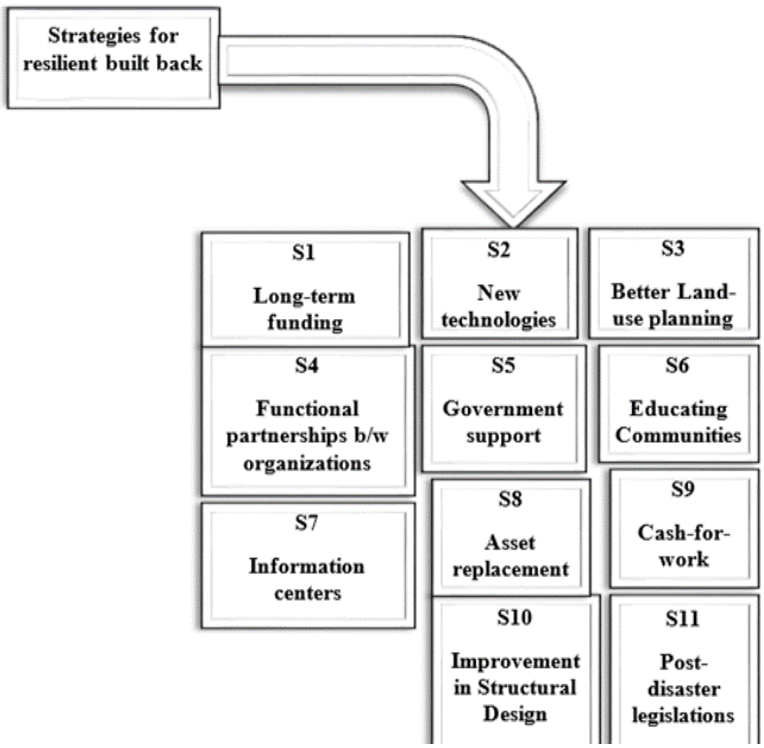

Figure 1 Strategies for Resilient Built Back in the Post-Flood Era

3. METHODOLOGY

3.1. Research Design

The research methodology of the study includes four main phases, as illustrated in Figure 2. Initially, in Phase I, group discussions were conducted with six (6) policymakers, eight (8) civil engineers, and five (5) Disaster Risk Reduction (DRR) experts in Pakistan. Alongside these discussions, an extensive literature review was undertaken to develop a detailed and effective questionnaire for gathering expert responses. This phase helped determine various construction-related causes of the Pakistani floods in 2022.

Subsequently, in Phase II, data collected from the literature review and expert discussions were analyzed to determine critical factors for proposing strategies aimed at BBB and enhancing resilience in post-disaster recovery efforts following the 2022 floods. Phase III involved using the Analytic Hierarchy Process (AHP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) analysis, a multi-criteria decision-making (MCDM) approach, to evaluate and rank these critical factors based on their weightage, subsequently categorizing them into cause-and-effect groups. Finally, in Phase IV, the results were synthesized, and the main findings were discussed, leading to the study's conclusions and implications.

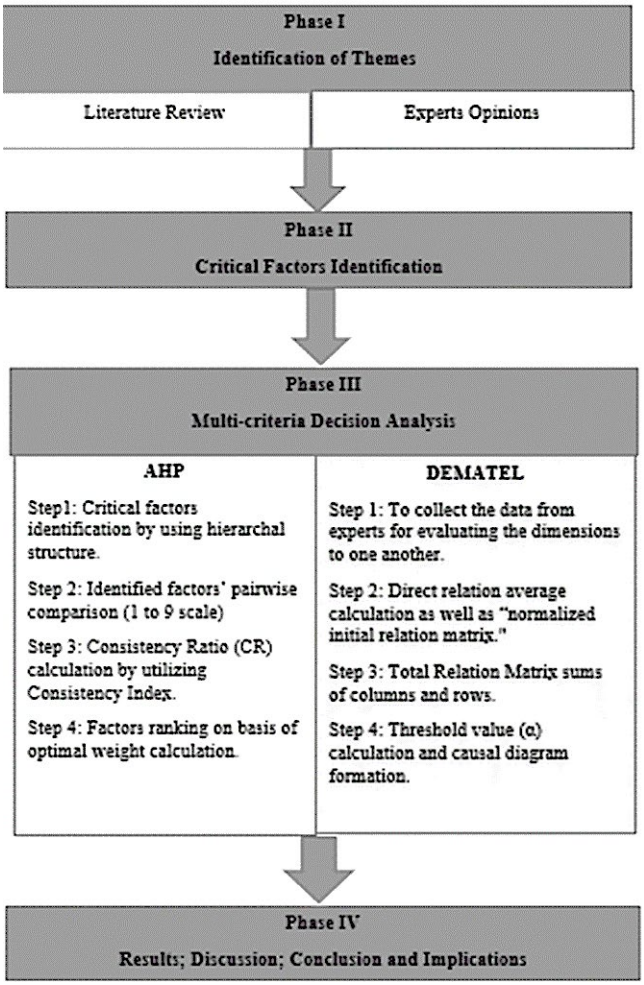

Figure 2 Research Methodology

3.2. AHP Methodology

The "Analytic Hierarchy Process" (AHP) method is considered an easy and effective mathematical tool (Andres et al., 2016; Arteeva & Skhvediani, 2021). It utilizes the concept of pair-wise comparison (PWC) of factors for solving multi-dimensional and complex problems by creating a hierarchical structure (Albayrak & Erensal, 2004). Initially, the AHP concept was used to determine military planning and resource allocation solutions. However, it is now widely used in various fields such as industry, engineering, health, education, and others. This method focuses on determining the relative significance or weights of tested factors, which helps rank these factors for making effective decisions (Cheng & Li, 2001). Consistency tests are used in this process to check transitivity, filtering out responses that are not consistent. The AHP method is considered beneficial over various MCDMs because it is flexible and ensures consistent results.

Many policymakers support this method for obtaining better and more reliable results and making better decisions.

3.3. Decision-Making Trial and Evaluation Laboratory (DEMATEL) Method

The "Decision-Making Trial and Evaluation Laboratory (DEMATEL)" technique was initially formulated by the Battelle Memorial Institute of Geneva Research Centre to visualize the structure of complex causal relationships using digraphs or matrices. This mathematical tool is widely used for solving and analyzing complex real-world problems (Gabus & Fontela, 1972). Real-world problems are solved by implementing multiple strategies in unison rather than focusing on a single strategy. It is critical to understand the significance of each strategy, and evaluation is done to determine the direct and indirect relationships between the involved strategy. In this method, a pair-wise comparison is made between various system parameters to assess causal interrelations between the factors.

This method also focuses on the degree of influence between the factors. A digraph or structural matrix is used to visually represent causal relationships, effectively segregating the factors into effect and cause groups. The digraph effectively identifies "the most influential parameter," which has the greatest influence potential. This facilitated effective decision-making and helped assess the influence of earlier decisions on building back better for the re-establishment and long-term recovery of communities affected by the 2022 Pakistani floods.

The literature review of the present study helped identify various construction-related causes of floods and suggest strategies regarding BBB. The practical implications of the strategies were found to be distinct for various organizations. The internal validity of the data was improved by conducting interviews and surveys with experts. It helped identify the practical applicability of the identified factors. A questionnaire was designed to gather expert opinions. The experts prioritized and assessed the factors to determine whether specific strategic interventions could be effective against future construction damages due to floods. Experts were asked about the construction-related causes of the 2022 floods and what strategies could prevent such issues in the future. They largely agreed that BBB is an effective framework for resilience building in the post-disaster recovery of the 2022 floods in Pakistan. They mainly focused on economic recovery, risk reduction, implementation, psychological recovery, and monitoring under this framework. The survey showed that experts strongly supported improvements in structural design and new technologies for the BBB method and resilience building in the post-recovery scenario.

After the survey was conducted using the formulated questionnaire, in-depth interviews were held with DRR experts, policymakers, and civil engineers regarding the practical applicability of the eleven identified factors in BBB post-disaster recovery of the 2022 floods in Pakistan. These factors included Long-term Funding (S1), New Technologies (S2), Better Land-use Planning (S3), Functional Partnerships between Organizations (S4), Government Support (S5), Educating Communities (S6), Information Centers Establishment (S7), Asset Replacement (S8), Cash-for-Work (S9), Improvement in Structural Design (S10), and Post-disaster Legislation (S11).

4. CASE STUDY

This section focuses on a case study regarding the Build Back Better (BBB) framework and resilience building in the post-disaster recovery of the 2022 floods in Pakistan. The case study was utilized to identify DRR) strategies by considering MCDM methods.

Increased climate change has resulted in various natural disasters such as floods, earthquakes, cyclones, and others, gaining the attention of professionals worldwide. The recent 2022 floods in Pakistan are a prime example of the growing frequency and severity of such natural disasters. Floods are among the most catastrophic events globally, with numerous countries experiencing extreme floods for various reasons over the past years. The 2022 floods in Pakistan were triggered by melting glaciers and heavier monsoon rains, both consequences of extreme climate change. These floods are considered among the deadliest in the world since the 2017 floods in South Asia. Approximately 1,569 people were killed, and the Pakistani government recorded losses of about US$40 billion. In addition to social losses, these floods inflicted significant damage on the construction sector.

The infrastructure of Pakistan was severely damaged by the 2022 floods, with the expected cost of reconstruction rising to $12 billion, twice the size of Pakistan's loan program with the International Monetary Fund (IMF), which is worth $6 billion. The reconstruction process is estimated to take two years. These devastating floods destroyed nearly 1,943,978 houses, 375 bridges, and 130,835 km of roads in various areas of Pakistan. According to Pakistan's National Disaster Management Authority (NDMA), about 778,560 houses were destroyed. The causes of these construction damages included poor structural designs, lack of better land-use planning, and the use of low-quality manufacturing products. Experts in the construction industry estimate that about $12.32 billion will be required for rebuilding and rehabilitating bridges, roads, and houses. These damages have not only impacted the economy but also the psychological well-being of the people.

Various short-term strategies are being considered to deal with the current state of Pakistan's infrastructure. However, the intervention of a long-term strategy is also necessary to promote BBB and resilience building in the post-disaster recovery from the 2022 floods in Pakistan. The earlier decisions on reestablishment and long-term recovery of the affected people are crucial for risk reduction and psychological recovery. Such strategies are also important for the country's economic recovery. Thus, the present study is effective in identifying important factors associated with BBB in the post-disaster recovery of the 2022 floods in Pakistan. This research also helps determine the practical implications of the identified factors, which could be essential for future flood resilience in Pakistan. It could also serve as an example for other countries suffering from similar natural disasters to take important and effective measures to promote and implement the BBB framework in their construction strategies.

5. RESULTS AND ANALYSIS

This section includes the numerical analysis of the identified factors using two main approaches: AHP analysis and DEMATEL analysis.

5.1. AHP Analysis

The AHP analysis helped prioritize the critical factors considered important for developing a BBB framework and building resilience against damages due to the 2022 floods in Pakistan. The experts' responses assisted in ranking the critical factors according to their normalized weights, as shown in Table 1, which shows that the most essential factor in BBB and resilience building for post-disaster recovery was Improvement in Structural Design (S10), with a weightage of 22%, ranking 1st among other factors. This factor plays a crucial role in enhancing the overall structural framework of various houses, roads, and bridges and promoting the quality of construction materials. The second most essential factor was Post-disaster Legislation (S11), with a weightage of 15%, ranking 2nd. A strong legal framework is vital for any institution's effective performance

and achieving positive outcomes. Similarly, new procedures need to be governed by laws and regulations for effective infrastructure development.

Functional Partnerships between Organizations (S4) ranked 3rd with a weightage of 13%. It has been observed that to address flood damages, various organizations need to promote partnerships to handle complex situations during post-disaster recovery. Other factors, such as New Technologies (S2) and Information Centers Establishment (S7), ranked 4th and 5th, with weights of 12% and 10%, respectively. This indicates that advanced technologies and machinery are essential for improving the country's infrastructure by building stronger roads and houses. These technologies also efficiently optimize construction operations for effective outcomes, resulting in risk reduction. The involvement of people is also crucial for psychological recovery, underscoring the importance of establishing information centers to provide important information to affected individuals.

Better Land-use Planning (S3) ranked 6th with a weightage of 6%, highlighting the need for better planning and frameworks to prevent construction damages from devastating floods. Cash-for-Work (S9) and Educating Communities (S6), weighing 6% and 7%, ranked 7th and 8th, respectively. During post-disaster recovery, the main focus is often on rebuilding damaged buildings, with less emphasis on economic recovery, resulting in a drop in employment rates. However, these factors are still essential for the BBB framework.

Government Support (S5) and Long-term Funding (S1) ranked 9th and 10th, weighing 4%. These factors are often neglected during post-disaster recovery, leading to issues in legislation and the functional performance of both national and international organizations. As a result, most construction sectors develop and implement their policies and procedures for better outcomes. Asset Replacement (S8) was the least focused factor, which hindered effective economic recovery. Asset replacement can lead to various complications, so other procedures, such as cash-for-work, are used to improve economic recovery during post-disaster recovery.

Table 1 AHP Analysis

Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Weight (%)	Rank
S1	1	1	0.33	7	0.33	0.33	0.2	0.33	0.2	0.33	0.33	4.0	10th
S2	5	5	3	1	1	3	1	5	1	3	1	12.0	4th
S3	1	5	0.2	3	5	0.33	3	0.2	3	0.2	0.14	6.0	6th
S4	1	3	7	5	7	1	5	1	1	5	0.2	13.0	3rd
S5	0.14	0.2	1	0.2	9	0.2	3	0.2	0.14	1	0.11	4.0	9th
S6	0.2	0.14	3	0.33	1	5	0.14	3	5	0.2	0.11	5.0	8th
S7	1	0.2	3	5	3	1	7	3	7	0.2	0.14	10.0	5th
S8	0.2	0.14	0.2	0.14	0.2	0.11	0.2	0.33	1	0.33	0.33	2.0	11th
S9	0.33	5	0.33	1	1	0.33	0.33	1	0.33	3	0.33	6.0	7th
S10	9	1	3	5	7	9	1	3	7	1	3	22.0	1st
S11	1	3	5	1	1	5	7	1	1	5	5	15.0	2nd

5.2. DEMATEL Analysis

In this study, the factors are segregated into "cause and effect groups" using the DEMATEL method, considering the related significance of the variables. After collecting responses from the experts, they were recorded as a direct relation matrix (A)"after a PWC as presented in Table 2. Subsequently, data redundancies were eliminated, and the Normalized Direct Relation Matrix (Z) is presented in Table 3. Table 4 represents the Total Relation Matrix (T), providing insight into

relationships between the identified factors and their indirect influences. In Table 5, values of R+C show the significance of the factors, while values of R–C indicate the factor's influence potential. If R–C > 0, the factor can impact other factors and is considered causal. Conversely, if R–C < 0, the factor is influenced by different factors and belongs to the effect group.

Table 2 Direct Relation Matrix (A)

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	0.001	3.91	1.91	2.21	0.801	1.91	1.82	0.81	1.09	3.11	3.32
S2	2.11	0.00	2.82	3.11	0.01	2.14	2.81	0.51	0.31	2.81	2.21
S3	2.11	2.91	0.00	2.81	2.21	1.73	2.34	1.10	0.21	2.91	2.11
S4	1.81	3.21	3.11	0.00	2.12	2.81	3.11	1.92	0.22	2.93	2.23
S5	0.11	0.61	0.81	1.21	0.00	3.92	4.13	2.14	0.31	1.81	1.31
S6	0.11	2.11	1.91	2.23	3.12	0.00	2.73	0.01	0.21	2.31	2.11
S7	0.31	1.91	2.11	2.31	4.11	2.11	0.01	1.81	0.22	2.11	1.22
S8	0.12	0.81	0.62	0.71	3.23	0.41	2.11	0.00	0.21	1.31	1.72
S9	2.11	3.21	3.02	3.22	1.12	3.12	1.91	3.11	0.01	3.21	3.81
S10	1.21	2.91	3.31	3.11	1.12	2.92	3.12	0.02	2.11	0.00	0.91
S11	1.91	1.81	2.31	2.11	2.11	3.12	3.02	1.12	2.88	3.09	0.01

Table 3 Normalized Direct Relation Matrix (Z)

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	0.001	0.141	0.071	0.081	0.031	0.071	0.071	0.031	0.041	0.111	0.121
S2	0.081	0.002	0.102	0.112	0.001	0.081	0.101	0.022	0.011	0.102	0.081
S3	0.081	0.112	0.003	0.102	0.083	0.06	0.081	0.041	0.011	0.111	0.081
S4	0.071	0.121	0.111	0.003	0.082	0.101	0.112	0.071	0.011	0.112	0.081
S5	0.004	0.023	0.032	0.042	0.001	0.141	0.151	0.081	0.012	0.071	0.052
S6	0.003	0.083	0.071	0.081	0.112	0.003	0.102	0.004	0.014	0.081	0.082
S7	0.012	0.071	0.081	0.081	0.151	0.081	0.001	0.071	0.012	0.081	0.041
S8	0.001	0.031	0.021	0.031	0.121	0.011	0.081	0.001	0.011	0.051	0.061
S9	0.081	0.121	0.112	0.121	0.041	0.112	0.071	0.112	0.001	0.121	0.141
S10	0.041	0.113	0.123	0.112	0.041	0.111	0.113	0.001	0.081	0.003	0.071
S11	0.071	0.071	0.081	0.081	0.081	0.112	0.113	0.041	0.112	0.113	0.002

Table 4 Total Relation Matrix (T)

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	-0.031	0.121	0.031	0.041	0.001	0.031	0.021	0.022	0.021	0.082	0.092
S2	0.062	-0.041	0.071	0.091	-0.041	0.051	0.072	0.012	0.002	0.071	0.052
S3	0.061	0.081	-0.041	0.071	0.061	0.021	0.041	0.031	-0.011	0.071	0.051
S4	0.051	0.081	0.082	-0.052	0.042	0.071	0.072	0.061	-0.012	0.071	0.052
S5	0.002	-0.011	0.001	0.021	-0.051	0.131	0.131	0.071	0.002	0.042	0.031
S6	-0.011	0.061	0.041	0.052	0.102	-0.041	0.061	-0.021	-0.011	0.061	0.061
S7	0.001	0.052	0.052	0.061	0.131	0.041	-0.051	0.052	0.001	0.051	0.021
S8	0.001	0.021	0.012	0.012	0.112	-0.021	0.052	-0.012	0.003	0.032	0.051
S9	0.051	0.072	0.072	0.081	0.001	0.071	0.011	0.101	-0.022	0.071	0.101

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S10	0.021	0.071	0.092	0.082	0.012	0.011	0.071	0.081	-0.032	-0.051	0.031
S11	0.051	0.021	0.052	0.031	0.043	0.081	0.072	0.021	0.102	0.071	-0.051

Table 5 Each Factor's Net and Total Effects

Critical Factors	R	C	R + C	R - C	Cause (C) or Effect (E)	Rank
S1	0.431	0.243	0.672	0.185	C	10th
S2	0.381	0.506	0.887	-0.122	E	5th
S3	0.431	0.448	0.878	-0.018	E	6th
S4	0.511	0.478	0.987	0.030	C	2nd
S5	0.357	0.401	0.756	-0.043	E	8th
S6	0.345	0.503	0.851	-0.157	E	7th
S7	0.393	0.558	0.954	-0.166	E	4th
S8	0.234	0.277	0.514	-0.044	E	11th
S9	0.595	0.148	0.742	0.443	C	9th
S10	0.441	0.551	0.989	-0.111	E	1st
S11	0.486	0.487	0.975	-0.003	E	3rd

From Table 5, it was observed that there were three causal factors, namely Long-term Funding (S1), Functional Partnerships between Organizations (S4), and Cash-for-Work (S9). At the same time, the remaining eight factors belonged to the effect group. These factors included New Technologies (S2), Better Land-use Planning (S3), Government Support (S5), Educating Communities (S6), Information Centers Establishment (S7), Asset Replacement (S8), Improvement in Structural Design (S10), and Post-disaster Legislation (S11). The value of R–C was the highest for Cash-for-Work (S9), indicating that this factor had a significant causal effect compared to other factors.

Table 6 presents the inner dependency matrix, in which elements of no significance are removed, as their values are less than the threshold value, $\alpha = 0.038$. Figure 3 illustrates the direction and nature of the relationships between the factors. Additionally, the pictorial representation of the factors based on the effect and cause groups, showing the relationship between total influence potential and net influence potential, is depicted in Figure 4.

Table 6 Inner Dependency Matrix

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	-	0.121	-	0.041	-	-	-	-	-	0.082	0.092
S2	0.062	-	0.071	0.091	-	0.051	0.072	-	-	0.071	0.052
S3	0.061	0.081	-	0.071	0.061	-	0.041	-	-	0.071	0.051
S4	0.051	0.081	0.082	-	0.042	0.071	0.072	0.061	-	0.071	0.052
S5	-	-	-	-	-	0.131	0.131	0.071	-	0.042	-
S6	-	0.061	0.041	0.052	0.102	-	0.061	-	-	0.061	0.061
S7	-	0.052	0.052	0.061	0.131	0.041	-	0.052	-	0.051	-
S8	-	-	-	-	0.112	-	0.052	-	-	-	0.051

Critical Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S9	0.051	0.072	0.072	0.081	-	0.071	-	0.101	-	0.071	0.101
S10	-	0.071	0.092	0.082	-	-	0.071	0.081	-	-	-
S11	0.051	-	0.052	-	0.043	0.081	0.072	-	0.102	0.071	-

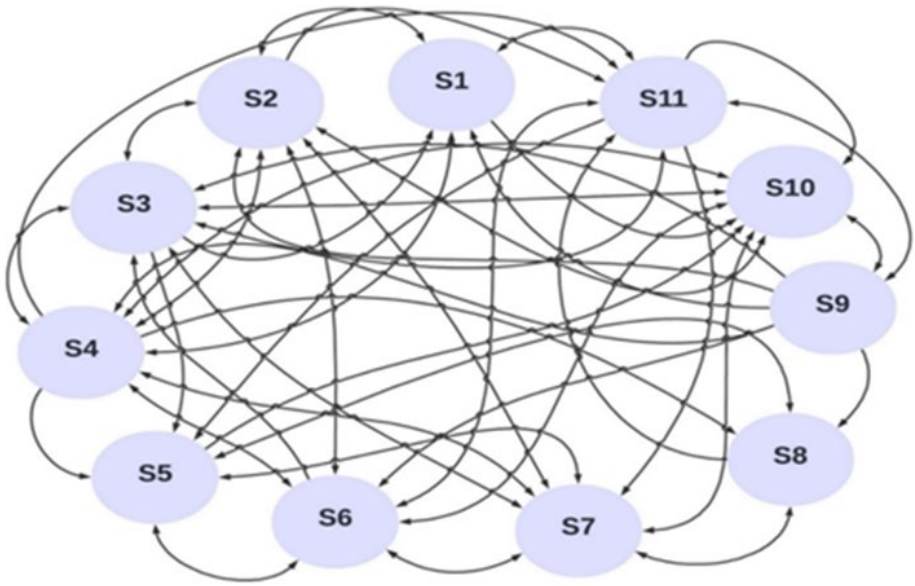

Figure 3 Critical Factors Diaphragm

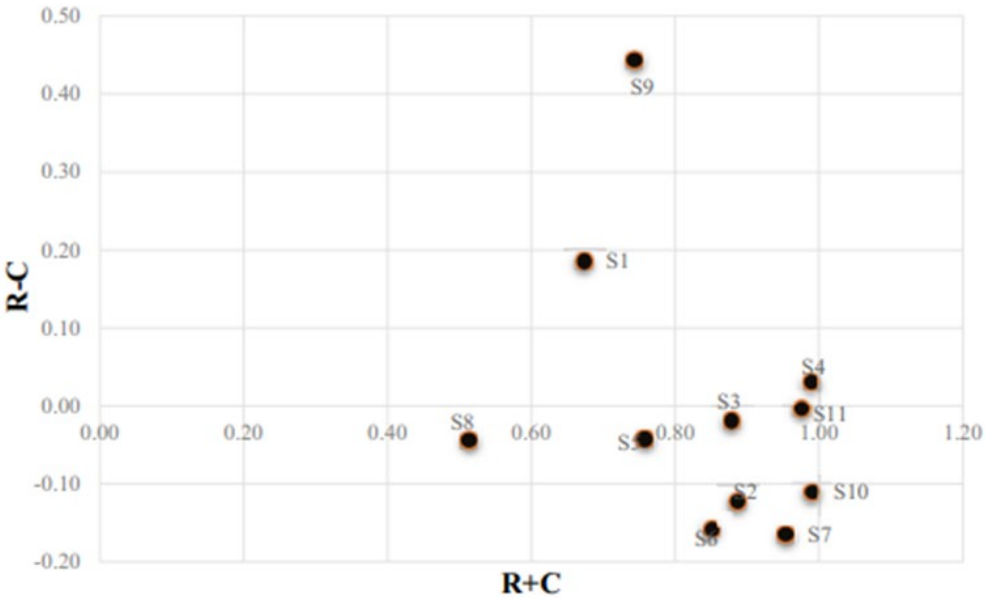

Figure 4 Critical Factors Diaphragm

6. DISCUSSION

The AHP analysis results reveal that the most significant factor for building back better in the post-flood era of Pakistan is Improvement in Structural Design (S10). Pakistan has a history of devastating floods and economic losses due to the collapse of buildings, a crucial element of the country's infrastructure (Warraich et al., 2011). For example, in SWAT, the "Honeymoon" hotel collapsed when floodwaters hit the area, primarily due to cheap materials, poor elevation, and the lack of pre-defined measures to address these disasters (Saeed Khan, 2019). Significant investments were lost due to the negligence of constructors and poor planning. Therefore, Improvement in Structural Designs (S10) is a crucial strategy that must be incorporated at any cost during construction. Past studies support the idea that using better materials and solid foundations for buildings with higher elevations should be mandatory (Auld, 2008). Quality materials should be used, and all necessary measures must be taken to prevent future losses from a structural design perspective (Foster et al., 2011).

Conversely, the least important factor from the AHP analysis is Asset Replacement (S8). According to Wijnia et al. (2006), asset replacement proves costly during rebuilding. Improved machinery and novel technology are needed when renovating or reconstructing a flood-hit area. The better approach is to take preventive measures during construction to ensure that buildings or assets have sufficient strength to withstand natural calamities (Haris et al., 2019). Replacing an asset results in higher costs and risks.

The DEMATEL analysis explored cause-and-effect factors. The results indicate that three causal factors significantly impact other factors for resilient build-back in post-flood areas of Pakistan: Cash-for-Work (S9), Long-term Funding (S1), and Educating Communities (S6). Cash-for-Work (S9) is the most important factor for constructing a resilient built-back environment in the post-flood area because finance and investment are critical resources. Resource availability ensures successful construction implementation, requiring improved raw materials, better processes, and enhanced systems. Long-term Funding (S1) is crucial, especially in areas of Pakistan that experience floods frequently. Floods in Pakistan occur almost every 2 to 3 years, causing unending devastation. More funding allocated towards reconstruction and better resource allocation significantly mitigate the overall impact of floods (Mannakkara & Wilkinson, 2013). Educating Communities (S6) is also an important factor, as better preparation and knowing how to respond in a flood-hit environment increase community safety and survival chances (Mannakkara et al., 2014). Educating communities helps reduce potential flood damage and enhances recovery efforts.

The three causal factors, Cash-for-Work (S9), Long-term Funding (S1), and Educating Communities (S6), influence the other factors to build a resilient environment in post-flood areas of Pakistan. These causal factors impact the effectiveness of other strategies for building back better. Improvement in Structural Design (S10) depends on available resources for reconstruction (Forster et al., 2022). This argument is supported by Ullah et al. (2021), who mentioned that increasing awareness (S6) is also an important effect factor by which people learn how to react during calamities. Similarly, the use of new technologies for building back better is an important factor from the effect group, influenced by the causal group factors (Luckham & Carter, 2022). Factors such as Functional Partnerships between Organizations (S4), Information Centers Establishment (S7), and Asset Replacement (S8) belong to the effect group and are significantly influenced by the causal factors.

7. CONCLUSION

This study aimed to identify and analyze the key factors that contribute to resilient reconstruction efforts in post-flood areas of Pakistan. The findings of the AHP analysis highlight Improvement in Structural Design (S10) as the most critical factor for resilient post-flood reconstruction in Pakistan, while Asset Replacement (S8) is deemed least important due to its high costs. The DEMATEL analysis identifies Cash-for-Work (S9), Long-term Funding (S1), and Educating Communities (S6) as key causal factors that significantly influence the effectiveness of other strategies for building a resilient environment in post-flood areas.

This study is significant as it contributes uniquely to the growing literature on the consequences and adversities caused by floods. Pakistan faces this calamity more frequently than other countries due to inadequate preventive measures. This study is relevant as it identifies the causes of floods and the best possible strategies to overcome deficiencies in the areas of Pakistan most affected by floods. Besides its contribution to literature, policymakers can use this study to effectively formulate supportive policies to combat floods. Another significant practical contribution of this research is identifying strategies for building a better environment socially, economically, and from a construction perspective. The results of ranking these strategies illustrate which are essential to consider reducing flood destruction further. Pakistan's government and regulatory bodies can also use this study to incorporate these factors for better build-back now, ensuring less damage and saving lives in the future.

While the government of Pakistan has been working tirelessly to raise funds and help flood victims, this study can assist in implementing these factors. Future researchers can alter the methodology used in this study to observe variations in results. This study can also be conducted in another flood-hit area by changing the context. Additionally, this study can be enhanced by using qualitative techniques such as expert interviews. The study's findings can also be generalized across different contexts to build a better resilient environment.

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DEVELOPING CONSTRUCTION SAFETY AUDITS WITH BUSINESS PROCESS MODEL AND NOTATION (BPMN): IMPROVING STAKEHOLDER COMMUNICATION AND COLLABORATION

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ABSTRACT

The significant increase in infrastructure development is directly proportional to the rising accident rate in the construction sector, making it one of the highest-risk sectors for accidents. This phenomenon indicates that existing construction safety audits have not been effective in preventing accidents, largely because audits are generally conducted only at the construction stage. Audits at the design stage, however, have the potential to impact accident prevention significantly. Therefore, this research aims to develop a construction safety audit model using the Business Process Model and Notation (BPMN) and analyzes the impacts on stakeholder communication and collaboration. BPMN was chosen because it provides a clear and standardized visual representation of business processes, making it easier to identify potential safety issues and improve stakeholder understanding. Statistical methods were employed to examine the relationships, resulting in a linear equation model with a strong correlation. Furthermore, audit activities conducted through three layers of stakeholders can be efficiently modeled using BPMN, positively impacting stakeholder communication and collaboration. Applying the Three Lines of Defense (TLoD) theory and BPMN provides new insights for construction safety committees and companies to plan and conduct more comprehensive safety audits. The implication of this study includes a potential reduction in construction accidents and improved work safety through more effective communication and collaboration among stakeholders.

Keywords: Process audit; Construction safety; BPMN; Communication; Collaboration

1. INTRODUCTION

Construction accidents and building failures are common in Indonesia. Many construction accidents with a high level of risk occur during the implementation phase, while instances of building failures arise after the final delivery of construction services. In 2023, the Social Security Administrator for Employment (BPJS Ketenagakerjaan) documented a total of 370,747 cases involving 41 million active participants. According to the Ministry of Labor of the Republic of Indonesia (2024), this corresponds to an estimated 84 claims for work accidents per 10,000 workers. Work-related accidents are common in the construction sector, as seen worldwide (Charoenloet et al., 2011). According to the European Agency for Safety and Health at Work (EU-OSHA, 2012), the construction industry is the most hazardous in terms of occupational safety and health. On a global scale, the mortality rate for construction workers is three times higher, and the rate of occupational injuries is twice as high compared to other sectors. Individuals

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who dedicate their professional lives to working on construction sites have a 1 in 300 probability of experiencing a fatal accident due to inadequate safety precautions (Bavafa et al., 2018).

Work environment factors can facilitate errors and violations by workers, often manifesting as unsafe actions such as disregarding safety rules and procedures. These dangerous acts frequently lead to work accidents. Work safety is a critical aspect that organizations must prioritize due to its direct impact on the well-being of workers (Ponda, 2020). A company's commitment to work safety significantly influences its overall safety performance (Satoto & Khoiroh, 2018). The audit process can assist companies in identifying factors causing work accidents. By conducting audits, companies can evaluate existing processes and determine whether they comply with occupational safety standards. Moreover, the results of Occupational Health and Safety (OHS) audits help companies develop standard checklists, provide improvement recommendations, enhance environmental, health, and safety performance, and reduce accident numbers (Robson & Bigelow, 2010; Siddiquia et al., 2014).

Despite the benefits, construction safety audits in the field have not been effective and optimal. The limited human resources of the Construction Safety Committee contribute to this inefficiency, especially given the large scale of projects under supervision. Furthermore, construction safety audits are often conducted only at the construction stage or post-accident rather than from the design stage. This focus on implementation methods means potential safety issues from the design stage may be overlooked. Formal safety guidelines for construction workers are scarce within design firms, with only 9.8% of engineers and 3.2% of architects reporting their existence (Tymvios & Gambatese, 2015). Correct application of audit standards improves audit quality (Pratistha & Widhiyani, 2014). Addressing construction safety issues early by enhancing stakeholder communication and coordination at the design and construction stages can prevent accidents and improve safety outcomes (Andi et al., 2005; Gambatese et al., 2008).

The audit procedure has been refined by integrating concepts from ISO 19011:2018 and the Regulation of Indonesia's Minister of Public Works and Housing Number 10 of 2021, leading to an enhanced construction safety audit structure. This refinement identified 34 tasks in audit program management, 34 tasks in audit execution, and 32 sub-components in audit standards, all integrated into the construction safety audit framework (Nugroho et al., 2024). The Construction Safety Plan, especially under the design-build method, has 36 key objectives and a safety program to manage high-level risks. Specifically, three high risks were identified during the design phase, two during the Construction Safety Management System implementation, and three during the construction phase (Akram et al., 2024).

Indonesia's commitment to advancing building and infrastructure development is exemplified by the various construction project developments. However, this accelerated development entails numerous risks, high complexity, and considerable uncertainty. The design-and-build method manages these challenges, allowing planners to contribute to construction safety through early interaction with contractors (Tymvios & Gambatese, 2015). This method, as defined by Regulation 25 of 2020 from the Minister of Public Works and Housing, involves a single contract for both design and construction, providing benefits such as single responsibility, faster implementation, cost savings, price certainty, buildability, and minimized claims (Xia et al., 2014; Alam, 2011). Nevertheless, many projects still encounter significant delays despite this method (Putro & Latief, 2020).

Modeling business processes is a management approach that helps organizations control and analyze their processes using methods, techniques, and software tools (Alotaibi, 2016; Indulska et al., 2009). Business process modeling, often used for evaluation and improvement, is a crucial first step in creating an integrated business information system (Yunis, 2010). Business Process Model and Notation (BPMN), a standardized method for representing business processes

graphically, serves as a visual blueprint for business operations (Owen & Raj, 2003; Mark Von Rosing & Henrik von Scheel, 2014; Krisantoso et al., 2015).

In Indonesia, BPMN is mandated by the government for all Ministries and Agencies to prepare business process maps, aiding in modeling processes for both technical and business users. BPMN is designed to be easily understood by all stakeholders. Therefore, this research addresses the need for clear and detailed descriptions at each stage of the audit process, facilitating stakeholder understanding and management of audit activities from initiation to closing. By meeting existing standards, the resulting BPMN model will visualize business processes more simply, enabling effective communication and stakeholder collaboration. This approach aims to address differences of opinion constructively, thereby improving the overall effectiveness of construction safety audits.

2. LITERATURE STUDY

A business process model consists of activity models and constraints between activity models (Decker et al., 2007). Business process maps are often used to cross-organizational functional boundaries and improve integration (Hassen et al., 2019). BPMN, developed by the Business Process Modeling Initiative (BPMI), is a methodology for modeling business. The BPMN specification provides a visual graphical representation of business processes in a Business Process Diagram (Simpson, 2004). BPMN aims to provide a notation that all business users easily understand and to ensure that Extensible Markup Language (XML) designed for business process execution can be expressed visually with a common notation (Owen & Raj, 2003). When using BPMN, a level 0 map, functioning similarly to a process map, provides an overall view of organizational activities akin to a helicopter perspective (Tukiran et al., 2023).

BPMN can be used to design business processes and identify potential problems. It also serves as a tool to enable business process implementers to communicate clearly, correctly, and efficiently (Maniah, 2017). Modeling languages that can describe business processes include Integration Definition for Function Modeling (IDEF), Event-Driven Process Chains (EPC), Activity Diagrams in the Unified Modeling Language (UML), Data Flow Diagrams (DFD), and BPMN. In Indonesia, BPMN is recommended as a notation for modeling business processes per the Guidelines for Structuring Management issued by the Minister of Administrative and Bureaucratic Reform (2018).

BPMN models can be created based on the actors and activities involved. The actors in this case are stakeholders involved in the construction safety audit, approached through the Project Management Body of Knowledge (PMBOK) and the Three Lines of Defense (TLoD) theory. As stated in the PMBOK, stakeholder engagement planning precedes stakeholder engagement management, which involves approaching stakeholders based on their needs, expectations, interests, and project impact. This process offers a comprehensive strategy for engaging stakeholders. The next phase, Stakeholder Engagement Management, involves effectively communicating and collaborating with stakeholders to identify issues, meet expectations, and encourage greater engagement, thereby leading to strengthened stakeholder support. The last phase, Monitoring Stakeholder Engagement, oversees interactions with stakeholders and revises engagement tactics to enhance stakeholder involvement.

The TLoD theory addresses how specific obligations related to risks and controls can be allocated within an organization, enhancing understanding of risk management and control by defining roles and duties. The model operates under the supervision of top management and the board of directors, with three separate bodies - or lines of defense - critical to effective risk management and control. The TLoD model is widely recognized as a framework for organizing the roles of internal audit functions and other governance stakeholders (Bantleon et al., 2021).

3. METHODS

The research methodology combines qualitative and quantitative techniques. It begins with a literature review and expert validation using the Delphi method to identify stakeholders and risk-based activities in construction safety audit processes. Following this, BPMN modeling and construct content validation were conducted. The collected data were then analyzed, and the results were presented in quantitative form. Figure 1 shows the research workflow.

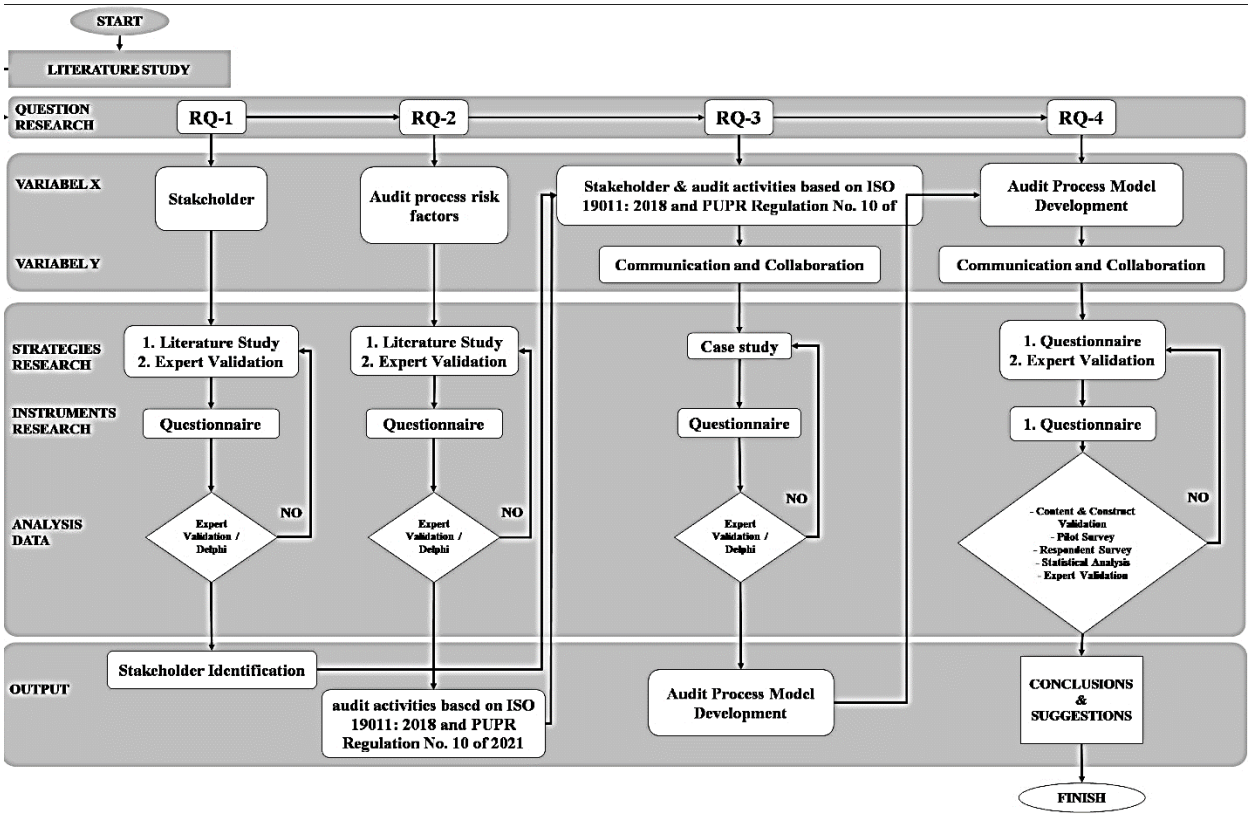

Figure 1 Research Stages Flowchart

The operational model of the research that illustrates the relationship between variable X and variable Y in the context of the audit process is shown in Figure 2. Variable X includes three main components: Stakeholders (X1), Risk-Based Audit Activities (X2), and BPMN Model on Audit Process (X3). These three components contribute to variable Y, which consists of Communication (Y1) and Collaboration (Y2). Stakeholders play an important role in supporting the audit process, while Risk-Based Audit Activities ensure the audit is conducted with risks in mind. Using BPMN in the audit process helps map and manage the audit process more systematically. Effective communication (Y1) between the parties involved enhances collaboration (Y2), which is critical to achieving optimal audit results.

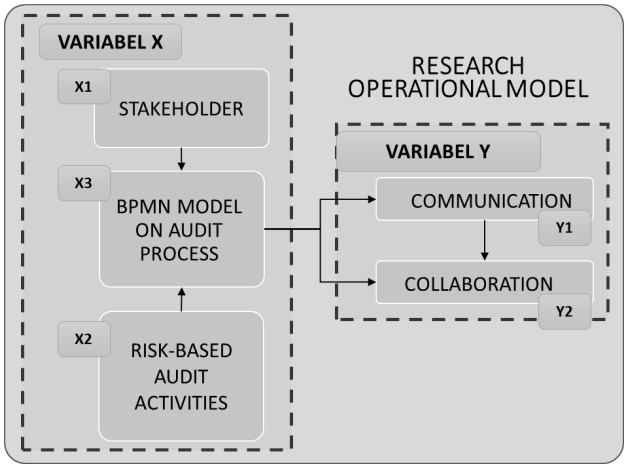

Figure 2 Conceptual Framework

3.1. Data Collection and Analysis Approach

A questionnaire was designed to capture independent and dependent variables derived from BPMN indicators, communication, and stakeholder collaboration. This questionnaire was distributed to 36 respondents from the construction sector, who were tasked with scoring and measuring the relationship between the construction safety audit BPMN model and communication and collaboration as quantitative data (see Table 1).

Table 1 Number of Respondents

No	Work Experience	Number of Respondents
1	<5 years	3
2	5 – 10 years	15
3	11 – 15 years	5
4	16 – 20 years	6
5	>20 years	7

Among the respondents, 64% hold a bachelor's degree, 33% have a master's degree, and 3% possess a doctoral degree. Regarding work experience, the majority (42%) have 5-10 years of experience. Additionally, Table 2 shows that the experts involved include five individuals with master's or doctoral degrees whose work experience ranges from 12 to 38 years.

Table 2 Number of Experts

No	Education	Work Experience
E1	Doctor	14 years
E2	Master	12 years
E3	Master	31 years
E4	Doctor	38 years
E5	Doctor	29 years

This research utilizes Structural Equation Modeling (SEM) with SPSS version 22 to analyze the influence of the BPMN model on stakeholder communication and collaboration. The stages of analysis include tests for homogeneity, data adequacy, validity, reliability, correlation, factor analysis, and regression. The result is a regression equation validated by experts to test the initial

hypothesis: applying the BPMN model to the audit process impacts communication and collaboration among construction safety stakeholders. Factor analysis helps identify areas where communication and collaboration between stakeholders can be improved, aligning with the research objective to enhance communication and collaboration in construction safety audits.

4. RESULTS AND DISCUSSION

4.1. Stakeholders and Activities

The stakeholders involved in the audit process for high-rise building design work are categorized into three lines, following the widely adopted TLoD theory in several institutions in Indonesia. The first line of stakeholders consists of the internal project team, which conducts a construction safety self-audit led by the project manager and supported by the head of the project construction safety unit. The second line involves the company level, where the Quality, Health, Safety, and Environment (QHSE) Bureau, through its internal auditors, performs audits on ongoing projects. The third and highest line of auditors is from the Minister of Public Works and Housing, represented by the Construction Safety Committee.

Regarding risk-based audit activities, literature studies and expert validation indicate that 102 audit activities must be performed. The TLoD model is widely recognized as a framework for defining the roles of the internal audit function and other governance stakeholders. While the benefits of TLoD are evident, experiences from companies, construction safety committees, and professional bodies highlight challenges in its implementation (Bantleon et al., 2021).

4.2. BPMN Modeling

After identifying stakeholders and risk-based activities, the next step was to develop a construction safety audit process model using the BPMN method. Experts validated this model according to the criteria stipulated in the Minister of Administrative Reform and Bureaucratic Reform Regulation No. 19/2018. These validation criteria are divided into three main parts: core, supporting, and other activities. The modeling process focused on the construction safety committee and included four main activities, eight supporting activities, and one other activity. Figure 3 illustrates the audit business process modeling of the construction safety committee. In contrast, Figure 4 presents a level 0 BPMN model of monitoring and evaluation activities within the core activities of the business process.

At the audit program stage, after setting the objectives and evaluating the risks and opportunities of the audit program, the next step is to implement the audit program. Details of the activities are contained in Figure 5, where the implementation of the audit program begins with setting the objectives and scope, determining the audit method, selecting audit team members, and managing and maintaining records of the audit program results. Once the audit team members are determined, the process continues, and audit implementation responsibilities are assigned to the leader.

This activity is detailed in Figure 6, starting with submitting a letter of assignment to the audit team by the construction safety committee. Upon receiving the assignment letter, the audit team initiates the audit by communicating with the auditee team from the project team or involving the QHSE department of the implementing company. The auditee team is asked to conduct a self-assessment based on the established audit criteria at this stage. The self-assessment results are then submitted into the construction safety audit system, facilitating access to preliminary data for the committee's audit team before conducting the on-site audit. Business Choreography (BC) in BPMN is very useful in coordinating the execution of various business processes, involving

different independent organizations running in parallel and interacting with each other and external partners to accomplish global tasks (Corneli et al., 2021).

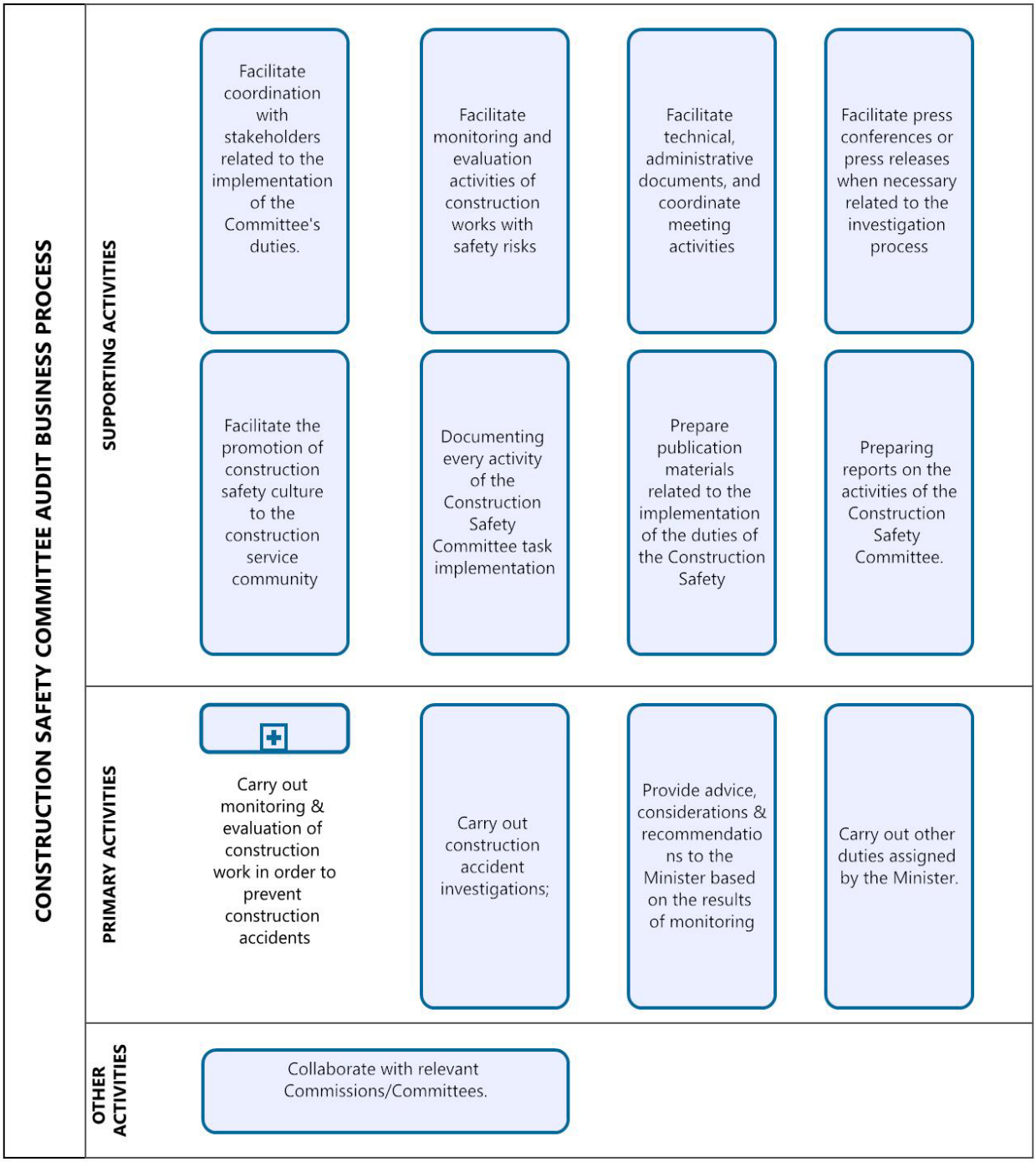

Figure 3 The Audit Business Process Modeling of The Construction Safety Committee

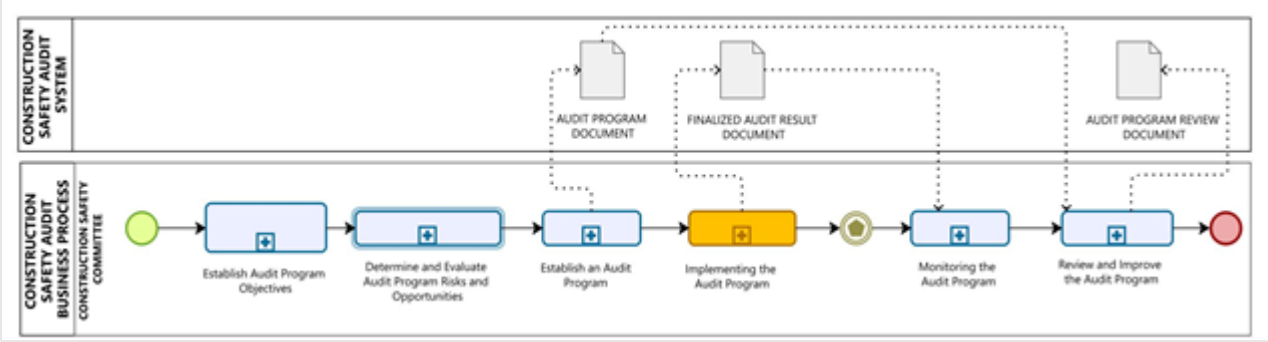

Figure 4 BPMN Model's Level 0 of Monitoring and Evaluation Activities

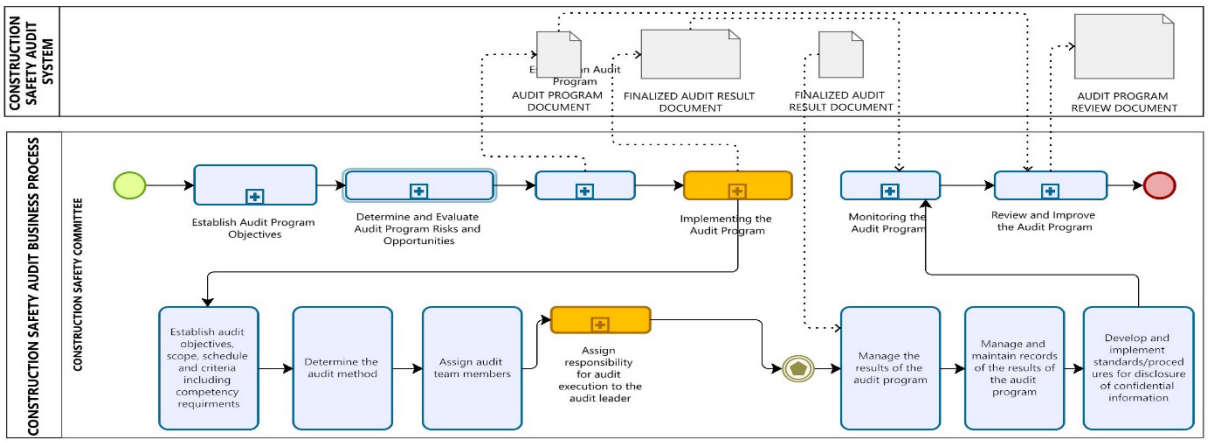

Figure 5 BPMN Model' Level 1 of Implementing the Audit Program

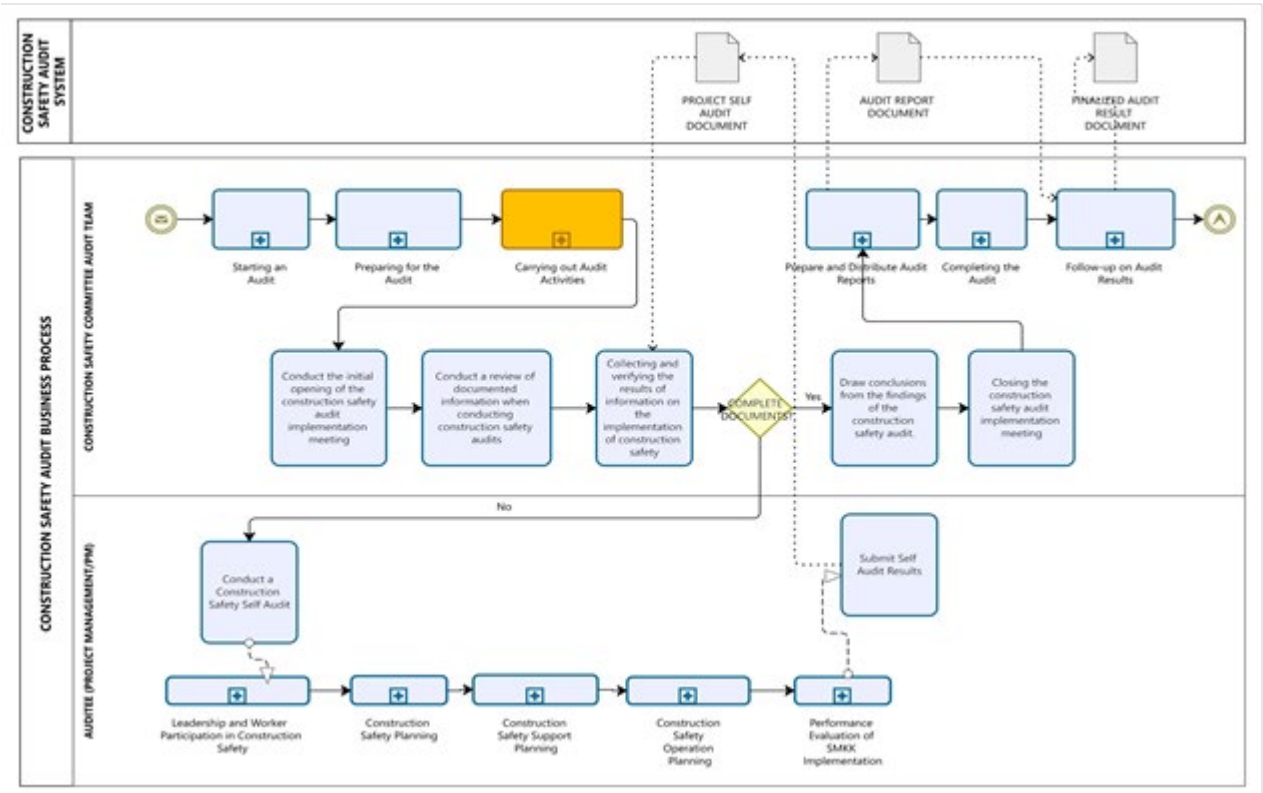

Figure 6 BPMN model's Level 2 of Audit Activity

4.3. Regression Analysis

The regression equation model is the main result of the statistical analysis conducted on 36 respondents. The regression analysis tested the coefficient of determination using the Nagelkerke R-squared model. This test was performed in two parts: variable X on communication (Y1) and variable X on collaboration (Y2),

From the results of multiple linear regression for variable X on communication (Table 3), it is found that all the factors formed have a significant impact, accounting for 69.1% of the variation in the dependent variable Y1 (Communication). It indicates that 30.9% of the variation in Communication is influenced by other variables not included in this study.

This value is an adjustment of the Cox and Snell R Square value, which ranges between 0 and 1 and facilitates interpretation (Table 4). The Nagelkerke R Square value of 0.993 indicates that the regression model explains about 99.3% of the variation in the collaboration variable (Y2). It is a very high value, indicating that the model effectively describes the variability in the collaboration data.

Table 3 R Square Regression Nagelkerke Variable X on Communication (Y1)

Cox and Snell	.452
Nagelkerke	.691
McFadden	.567

Table 4 R Square Regression Nagelkerke Variable X on Communication (Y1)

Cox and Snell	.452
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The general form of a multiple linear regression model is as follows:

$$\mathbf{Y' = a + b1X1 + b2X2 + b3X3 + \ldots + bnXn} \quad \mathbf{(1)}$$

Where: Y' is the dependent variable (predicted value), while X1 and X2 are the independent variables. The constant, denoted as 'a,' represents the Y value when X1, X2, and other variables equal zero. The regression coefficient, denoted as 'b,' indicates the increase or decrease in the value of Y' based on changes in the independent variables. The regression Coefficient of the BPMN Variable Audit Process on Communication (Y1) is summarized in Table 5.

Table 5 Regression Coefficient of BPMN Variable Audit Process on Communication (Y1)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	**4.915**	.223		22.071	.000
	X3Y1.1	.007	.050	.049	.138	.891
	X3Y1.2	-.011	.039	-.088	-.291	.774
	X3Y1.3	-.005	.041	-.045	-.124	.902
	X3Y1.4	.012	.045	**.110**	.274	.786
	X2Y1.1	.031	.043	**.224**	.731	.472
	X2Y1.2	-.016	.047	-.095	-.340	.737
	X2Y1.3	-.047	.041	-.293	-1.152	.260
	X1Y1.1	1.721E-05	.043	.000	.000	1.000
	X1Y1.2	.018	.038	.137	.464	.647
	X1Y1.3	.024	.050	**.170**	.474	.640

From Table 5, several conclusions can be drawn. The regression equation obtained is Y1 = 4.915 + 0.0187X1 + 0.0242X2. This equation indicates that the constant value is 4.915, meaning that if both factors (X1 and X2) are zero, the value of Y1 will be 4.915. The regression coefficient for the stakeholder factor and risk-based activities is 0.0187, which implies that if the other independent variables remain constant, a 1% increase in the stakeholder factor and risk-based activities will result in a 0.0187 increase in the communication variable (Y1). Similarly, the regression coefficient for the BPMN factor is 0.0242, indicating that if all other independent variables remain constant, a 1% increase in the BPMN factor will lead to a 0.0242 increase in the communication variable (Y1).

Furthermore, multiple linear regression was also conducted to construct risk-based BPMN models on collaboration (see Table 6). The analysis results using the SPSS version 22 program are as follows: The regression equation obtained from Table 6 can be expressed as Y2 = 0.571 + 0.0482X1 + 0.1079X2. The constant value is 0.571, indicating that if both factors (X1 and X2) are zero, the value of Y2 will be 0.571. The regression coefficient for the stakeholder factor and risk-based activities is 0.0482. If all other independent variables stay the same, a 1% rise in the stakeholder factor and risk-based activities will lead to a 0.0482 increase in the cooperation variable (Y2). Similarly, the regression coefficient for the BPMN factor is 0.1079, indicating that if all other independent variables remain constant, a 1% increase in the BPMN factor will lead to a 0.1079 increase in the collaboration variable (Y2).

Table 6 Regression Coefficient of Audit Process BPMN Variables on Collaboration (Y2)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	**.571**	.925		.617	.543
	X2Y2.1	.114	.221	.124	.516	.611
	X2Y2.2	.054	.225	.052	.242	.811
	X2Y2.3	.484	.205	.461	2.355	.027
	X1Y2.1	-.108	.285	**-.093**	-.378	.709
	X1Y2.2	.186	.240	**.206**	.775	.446
	X1Y2.3	-.045	.246	-.046	-.181	.858
	X3Y2.1	.075	.238	.078	.317	.754
	X3Y2.2	.198	.187	**.234**	1.062	.298
	X3Y2.3	.030	.221	.037	.136	.893
	X3Y2.4	-.142	.214	**-.184**	-.662	.514

4.4. Multiple Correlation Analysis (F Test)

Multiple correlation analysis is used to determine the strength and contribution of two or more independent variables simultaneously to the dependent variable (Raharjo, 2014). This test aims to assess whether all the coefficients of the independent variables in the BPMN factor of the dominant risk-based audit process have a significant simultaneous effect on stakeholder communication and collaboration.

The basis for making decisions in multiple correlation analysis is as follows: if the probability value is greater than 0.05 (0.05 < Sig probability value), then the null hypothesis (Ho) is accepted and the alternative hypothesis (Ha) is rejected, indicating no significant relationship between variable X and variable Y. Conversely, if the probability value is less than 0.05 (0.05 > Sig probability value), then Ho is rejected and Ha is accepted, indicating a significant relationship between variable X and variable Y.

Multiple correlation analysis was conducted in two parts: between variable X and Y1 (communication) and between variable X and Y2 (collaboration). The results of the multiple correlation analysis between variable X and Y1 (communication) are presented in Table 7.

Table 7 Results of Multiple Correlation Analysis between Variable X on Y1

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	.193	1	.193	117.068	.000[b]
Residual	.056	34	.002		
Total	.249	35			

This study aimed to investigate the effects of the BPMN risk-based audit process on communication. The null hypothesis (Ho) states that if the significance (Sig) value is over 0.05, the BPMN risk-based audit procedure has no meaningful impact on communication. In contrast, the alternative hypothesis (Ha) states that when the Sig value is below 0.05, the BPMN risk-based audit process substantially impacts communication. The null hypothesis would be accepted if the F count is less than the F table value. Conversely, if the F count exceeds the F table value, the null hypothesis would be rejected.

The F value was evaluated using SPSS version 22 to examine these hypotheses. The findings of the multiple correlation analysis showed that the significance probability value was below 0.05, precisely 0.000. The calculated F value was 117.068, which exceeds the critical F value (a = 5%, df1 = 1, df2 = 34, F table = 4.1300). This finding illustrates a substantial impact of the stakeholder factor, risk-based activities, and the BPMN model on the communication variable (Y1).

Next, multiple correlation analyses were conducted between variables X and Y2 (collaboration). The results of this analysis are presented in Table 8. Based on this hypothesis, the F value was tested using SPSS version 22. The results of the multiple correlation analysis (Table 8) show that the Sig probability value is less than 0.05, specifically 0.000. The F value obtained is 16.406, greater than the F table value (a = 5%, df1 = 2, df2 = 33, F table = 3.2849). It indicates a significant influence of the stakeholder factor, risk-based activities, and the BPMN model on variable Y2 (Collaboration).

Table 8 Results of Multiple Correlation Analysis between Variable X on Y2

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.288	1	3.288	12.742	.001b
	Residual	8.773	34	.258		
	Total	12.061	35			
2	Regression	6.013	2	3.007	**16.406**	**.000c**
	Residual	6.048	33	.183		
	Total	12.061	35			

4.4. Discussion

The model development is based on stakeholder groupings and risk-based audit activities validated by experts. The BPMN model has also been validated by experts according to the criteria outlined in the Regulation of the Minister of Administrative and Bureaucratic Reform of the Republic of Indonesia Number 19 of 2018. During the level 2 audit process, self-audit activities are added for the auditee of the project team, referring to the five audit criteria from the Regulation of the Minister of Public Works and Housing Number 10 of 2021. The audit data is

then uploaded into the construction safety audit system, enabling auditors to carry out subsequent audit processes efficiently, supporting paperless work initiatives, and saving time.

The main result of the statistical analysis is the regression equation model. The regression analysis performed on variable Y and variable X shows a positive relationship between the independent variables (stakeholder factors, risk-based activities, and BPMN modeling factors) and the dependent variables (communication and collaboration). Both factors positively influence communication and collaboration in construction safety audits, with the BPMN factor showing a greater influence on both dependent variables than the stakeholder and risk-based activity factors.

The findings suggest that using BPMN models in the audit process can improve communication and collaboration among stakeholders in construction safety audits. The clear and standardized process visualization provided by the BPMN factor helps optimize the audit process, improve stakeholder understanding, and facilitate better documentation. Similarly, implementing the TLoD theory has unified several lines of construction safety auditing, resulting in improved stakeholder collaboration. Thus, this research makes an important contribution to improving the effectiveness of construction safety audits by applying the BPMN model and an integrated risk-based approach.

5. CONCLUSION

This study addressed the critical issue of construction safety, particularly in Indonesia, where construction accidents are prevalent due to inadequate safety measures. The study aimed to create a construction safety audit model utilizing the BPMN to enhance stakeholder communication and collaboration, improving overall safety performance. The results demonstrate that the BPMN model, validated by experts and following current regulations, successfully facilitates the audit procedure. The statistical study revealed a positive correlation between the independent variables (stakeholder factors, risk-based activities, and BPMN modeling elements) and the dependent variables (communication and collaboration). More precisely, the BPMN component had a stronger impact on communication and collaboration than the other elements. These findings demonstrate that the use of BPMN, which offers a clear and standardized way to visualize processes, greatly improves the efficiency of the audit process, boosts stakeholders' comprehension, and promotes more thorough documentation.

6. ACKNOWLEDGEMENT

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THE ROLE OF STAKEHOLDER INVOLVEMENT IN ENHANCING SAFE DRINKING WATER INFRASTRUCTURE: AN INTERPRETATIVE STRUCTURAL MODELING APPROACH

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ABSTRACT

One of the primary goals listed in the Sustainable Development Goals (SDGs) is to "Achieve universal and equitable access to safe and affordable drinking water for all," as stated in SDG 6.1. To obtain this goal, the Government of Indonesia has developed the 2020-2024 National Medium-Term Development Plan (RPJMN), which has set specific targets including achieving 100% access to decent drinking water, 15% access to safe drinking water, and establishing 10 million house connections. The Ministry of National Development Planning has established a goal of achieving 45% access to safe drinking water by 2030 as part of the SDGs. However, as per the World Health Organization (WHO), Indonesia is projected to attain a 30% level of access to safe drinking water by 2022, which falls short of the objective set for 2030. Therefore, this study aims to identify the stakeholders involved in achieving safe drinking water goals and the factors that affect the achievement of access to safe drinking water. The methods employed include interviews to identify and map stakeholders, Geometric Mean (GM) analysis to assess the level of influence and interest of stakeholders, and Interpretative Structural Modelling (ISM) to determine the influence level of each factor. The findings reveal that seven agencies are involved as stakeholders. The primary stakeholders in the "Manage Closely" quadrant include the Ministry of National Development Planning, the Ministry of Public Works and Housing, and the Local Government. Additionally, 23 factors were found to have an impact on the provision of safe drinking water. The ISM analysis indicated that the most influential factors were "Restrictions on authority related to regional autonomy and power sharing between institutions/ministries," "The number of stakeholders involved," and "Regulations and policies related to the procurement of safe drinking water supply."

Keywords: Interpretative structural modelling; Safe drinking water infrastructure; Stakeholder management

1. INTRODUCTION

Clean or drinking water is a fundamental and indispensable requirement for human survival, on par with food and air. The significance of water for human survival is emphasized by a 2015 WHO report, which states that one in three deaths in developing countries and 80% of diseases in these regions are linked to water quality and availability (WHO, 2017). The critical need for water and its role in human life form the basis for the Sustainable Development Goals (SDGs) 2030, which succeeded the Millennium Development Goals in 2015. SDG 6 focuses on ensuring sustainable water and sanitation for all, with the first target aiming for "universal and equitable access to safe and affordable drinking water for all," aiming for over 99% population coverage.

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By 2022, 2.2 billion people worldwide still lacked access to safe drinking water, with significant disparities between urban and rural areas (WHO, 2023). In Indonesia, a developing country with a growing population, the government has mandated the provision of safe drinking water as per the 1945 Constitution and Law No.17 of 2019. However, progress suggests that Indonesia will not meet the 100% safe drinking water access target by 2030 without significantly accelerating efforts (BPS, 2021; Purwanto, 2020). The complexity of achieving safe drinking water access necessitates a comprehensive analysis to identify effective solutions.

Previous research indicates that investment in water infrastructure has a crucial impact on the welfare of rural communities (Brown & Green, 2018). In addition, to improve access to drinking water infrastructure, sustainable water management, stakeholder engagement, and international collaboration are required (Kim & Lee, 2021; Johnson & Williams, 2019; Smith, 2020; Ihugba, 2012; Smith & Brown, 2022; Maylor, 2003; Wakka, 2014, Pahl-Wostl et al., 2018). Despite extensive research, there is still a gap in studies on stakeholder involvement in safe drinking water, especially in Indonesia.

This research provides a platform to enhance the understanding of the complexities involved in ensuring access to safe drinking water in Indonesia. The objectives of this study are to identify the stakeholders involved and their roles in achieving universal safe drinking water access by 2030, determine the priority factors in decision-making to meet this target, and design a stakeholder engagement plan to enhance the coverage of safe drinking water in Indonesia. This study employs a mixed-methods approach that combines qualitative and quantitative analyses and utilizes Interpretative Structural Modeling (ISM) to obtain its objectives.

This study is expected to provide valuable insights and references for further research on Indonesia's water access conditions and the roles of stakeholders in supporting this goal. The research is limited to the conditions of safe drinking water access in Indonesia during the study period, focusing on efforts to achieve SDG 6.1 by 2030 through a stakeholder approach. Furthermore, this paper specifically examines the role of stakeholder involvement in this process.

2. LITERATURE STUDY

According to WHO (2017), water is crucial for human life and must be consistently available, adequate, safe, and accessible. As defined by the Ministry of Health and the UN, clean water is essential for daily needs and a basic human right (Khalifa & Bidaisee, 2018). Hunter (2001) emphasizes that clean water availability significantly impacts regional populations, especially as populations grow, increasing the demand for clean water (BPSDM, 2018).

Access to clean water is influenced by various factors, including physical, geopolitical, and socio-economic conditions (Khalifa & Bidaisee, 2018). Drinking water differs from clean water, with the latter needing to meet specific criteria, including availability without travel, continuous presence, and freedom from harmful contaminants (Jauhari, 2021), with additional criteria from WHO (2017) regarding distance and travel time to the water source.

In 2017, WHO defined three criteria for evaluating access to drinking water: on-premises access, availability when needed, and freedom from contamination. These criteria led to the establishment of five levels of water provision in the 2023 Joint Monitoring Programme. In Indonesia, water provision is governed by Law No. 23 of 2014 and Government Regulation No. 122 of 2015. Two systems are used, Piped and Non-Piped, and responsibility is shared between central and local governments.

Drinking water supply systems, as mandated by Indonesian Government Regulation No. 122 of 2015, involve the establishment of State-Owned Enterprises and Regional-Owned Enterprises. Additionally, communities or businesses can provide drinking water supply systems, with

businesses restricted to meeting basic needs. Drinking water supply system development includes construction, capacity enhancement, and distribution unit expansion, while management involves operational maintenance, repairs, human resource development, and institutional development (Misser et al., 2015)

Stakeholder involvement, as defined by Pedrini et al. (2019), entails engaging relevant parties in organizational objectives and outcomes, representing a broad and ongoing process across organizations. Castelli et al. (2014) describe stakeholders as individuals or entities with goals and interests. Hendry et al. (2020) assert that stakeholders directly influence or are influenced by objectives-related policies. Jayasena et al. (2019) elaborated that stakeholder management aims to achieve goals amidst high complexity and competition.

Stakeholder engagement theory suggests that individuals or groups can influence or be influenced by the success of a common goal (Freeman, 1984; Chandra et al., 2011). Bourne (2015) further explains this as the effective acquisition of stakeholders' perspectives and their positive involvement in organizational activities. Sequeira and Warner (2007) and PMI (2017) have identified and outlined the key components of stakeholder engagement, which include identifying and analyzing stakeholders, disclosing information to stakeholders, consulting with stakeholders, negotiating and forming partnerships, being responsive to stakeholder concerns, involving stakeholders in decision-making, reporting to stakeholders, and performing management functions.

3. METHODS

This study aims to identify and map stakeholders and the factors influencing safe drinking water infrastructure fulfillment. Several analyses were conducted in this study to obtain this objective, including semi structural interview, power and interest scale, stakeholder mapping, ISM analysis, followed by stakeholder involvement analysis.

Semi-structured interviews were conducted with 11 respondents representing seven agencies fulfilling safe drinking water infrastructure, aiming to identify the stakeholders involved, their duties and authority, and to conduct stakeholder mapping. Additionally, data were collected to assess each stakeholder's level of interest and influence. Respondents rated these factors on a 1-5 scale, and the average results were mapped in a four-quadrant matrix known as the stakeholder mapping matrix.

The analysis method employed in this research is Interpretative Structural Modeling (ISM), supported by Geometric Mean (GM) analysis. The GM method calculates the square root of the product of all obtained values, determining which variables will be used for ISM analysis. Variables with a value greater than 3.5 were selected for ISM analysis. The variable assessment weighting process utilized a Likert scale, a 1-5 rating scale expressing the level of agreement.

The ISM method organizes and directs the complexity of relationships between elements in a system (Tan et al., 2019; Sandbhor & Botre, 2014). It is interpretative because the group's judgment determines the variables and their relationships, and it is structural because it extracts the structure from the complexity of the variables. This modeling technique is depicted in a graphical model (Singh and Kant, 2008)

The ISM questionnaire was prepared based on the geometric mean analysis results and then distributed to respondents. The analysis involved compiling a Structural Self-Interaction Matrix (SSIM) and a Reachability Matrix (RM). The SSIM matrix, generated by ISM tool, combines the results of all respondents' questionnaires into one matrix, denoted by the symbols V, A, X, and O under the following conditions:

V = When variable i leads to variable j, but variable j does not lead to variable i
A = When variable j leads to variable i, but variable i does not lead to variable j
X = When variable i leads to variable j and variable j leads to variable i
O = When the variables are not related

The Reachability Matrix (RM) is derived from the SSIM, converting symbols V, A, X, and O into numbers 0 and 1. A value of 1 indicates a relationship between i and j, while a value of 0 indicates no relationship. Based on the RM, the Driver Power and Dependence values were calculated to generate a variable ISM analysis results reveal the level of factors affecting the fulfillment of safe drinking water infrastructure. The workflow of this research is illustrated in Figure 1.

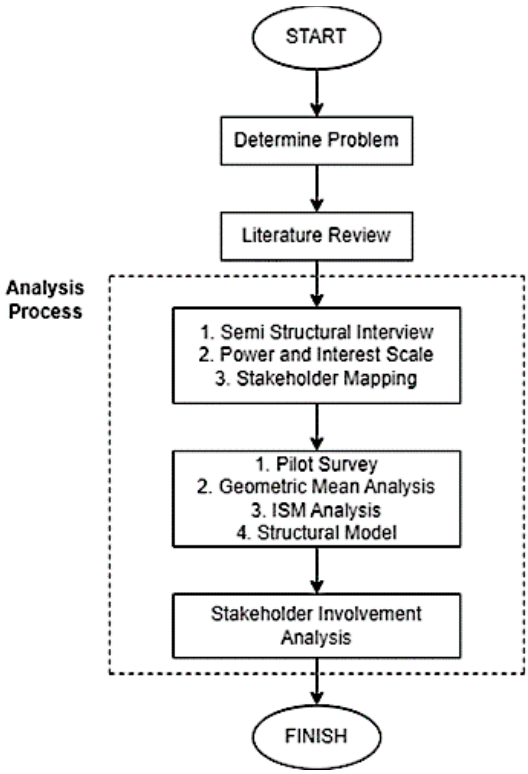

Figure 1 Workflow of the Research

4. RESULTS AND DISCUSSION

Semi-structured interviews were conducted from March to May 2024 with the stakeholders from seven ministries/agencies involved in the safe drinking water process, focusing on each stakeholder's role and challenges in implementing safe drinking water provisions in Indonesia. The interviews led to three key conclusions regarding the process of fulfilling safe drinking water: the number of parties involved, the high investment value, and the community's understanding of the importance of access to safe drinking water.

The process of developing drinking water infrastructure requires very high costs. The costs needed for construction are much greater than the operational costs. The government has supported this financing through several delivery systems, such as the construction of raw water infrastructure and water management facilities by the central government. However, this support does not reduce the financial burden on regions to operate piped water systems. For regions with substantial budgets, this challenge is mitigated, but for regions with limited budgets and without assistance from the central government, the provision of drinking water remains difficult.

Furthermore, the understanding and acceptance of the community regarding the efforts to provide drinking water infrastructure are still low. Many communities are not yet served by piped water systems, either for clean water or drinking water needs, causing a low level of understanding and acceptance of the community towards efforts to provide better drinking water infrastructure through piped networks. Many community members reject these efforts because they feel that connecting to piped water will incur high costs. This negative stigma related to costs hampers the community's ability and willingness to participate in this initiative. In areas not yet facilitated by piped water networks, residents use river water and groundwater, which they consider having the same quality and quantity but are free of charge. Even in areas with piped water infrastructure, many residents do not utilize it due to cost reasons.

Additionally, data were collected to measure the influence and interest levels of each ministry/agency using a Likert scale questionnaire. This questionnaire was administered to 11 stakeholders from seven ministries/agencies. The analysis revealed that local governments and the Ministry of National Development Planning have the highest influence. At the same time, the Ministry of Public Works and Housing shows the highest interest, aligning with their roles in infrastructure development and planning. The analysis results summarizing each stakeholder's interest and influence values are classify in quadrants as shown in Table 1.

Table 1 Stakeholder Influence and Interest Level

Stakeholder	Code	Power	Interest	Quadrant
Ministry of National Development Planning	S1	4.36	4.36	Manage Closely
Ministry of Public Works and Housing	S2	4.18	4.45	Manage Closely
Ministry of Finance	S3	4.27	3.00	Keep Satisfied
Ministry of Home Affairs	S4	2.82	2.55	Monitor
Ministry of Health	S5	3.00	3.45	Monitor
Local Government	S6	4.55	4.36	Manage Closely
Water Company	S7	2.45	4.36	Keep Informed

The stakeholder's interest and influence values are then mapped in a matrix shown in Figure 2, indicating that the seven stakeholders are distributed across four quadrants. The "monitor" quadrant, characterized by low interest and influence values, includes the Ministry of Home Affairs and Health. The "keep informed" quadrant, with high interest but low influence, consists of the Water Company. The "keep satisfied" quadrant, which has a high influence but low interest, includes the Ministry of Finance. Finally, the "manage closely" quadrant, with both high interest and influence, consists of the Ministry of National Development Planning, the Ministry of Public Works and Housing, and the Local Government.

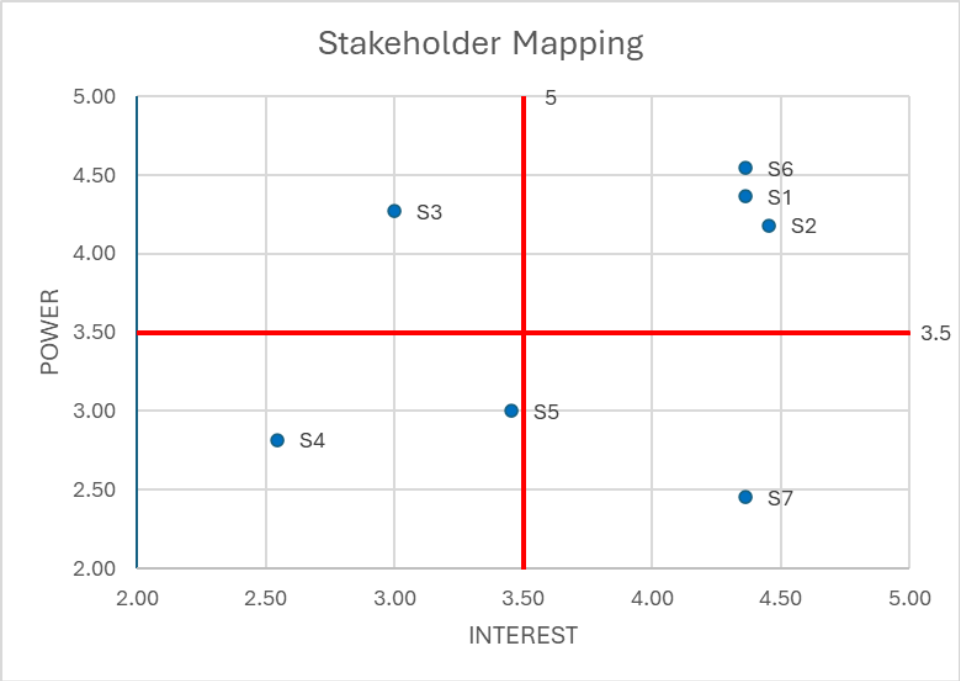

Figure 2 Stakeholder Mapping Matrix

Based on the literature review conducted, the factors influencing the prioritization in decision-making to enhance the coverage of safe drinking water were identified. Subsequently, these factors were prepared as variables in the GM questionnaire, used to determine the inputs for the ISM analysis.

Table 2 Analysis of The Geometric Mean

Variable	Code	Sub variable	Geometric Mean	Remark
Division of Authority and Political Conditions	V1	Limitations of authority related to regional autonomy and the division of power between institutions/ministries.	4.7	Fulfilled
	V2	The number of stakeholders involved	4.8	Fulfilled
	V3	Management of regional interests determined by regional leaders	4.0	Fulfilled
	V4	Differences in political policy directions in each region	4.0	Fulfilled
	V5	Collaboration between regions	3.7	Fulfilled
Document and Regulations	V6	Consistency of spatial planning documents and availability of Jakstrada	4.4	Fulfilled
	V7	Regulations and policies related to the provision of safe drinking water supply	4.3	Fulfilled
	V8	Availability of regulations supporting corporate investment	4.1	Fulfilled
Funding	V9	High investment value	4.3	Fulfilled
	V10	Limitation of funds, both at the national and regional levels	4.3	Fulfilled
	V11	Less-utilized investment schemes	4.1	Fulfilled
Type of Interaction	V12	Collaboration among stakeholders and governance systems that are not highly hierarchical, involving multiple centers of	4.3	Fulfilled

Variable	Code	Sub variable	Geometric Mean	Remark
		power and many institutions without rigid structures		
	V13	Partnerships between government and non-government entities in every process, being inclusive	4.0	Fulfilled
	V14	Hierarchy formed among stakeholder levels	4.5	Fulfilled
	V15	Policy-making networks	4.4	Fulfilled
	V16	Coordination as part of planning procedures	3.5	Fulfilled
	V17	Exchange of information and knowledge	3.6	Fulfilled
	V18	Ability to influence government affairs	3.7	Fulfilled
	V19	Engagement in planning activities	3.6	Fulfilled
	V20	Utilization of economic instruments as a basis for policy-making	3.7	Fulfilled
Stakeholder Involvement	V21	Playing a significant role in formulating or intervening in policies or regulations	4.5	Fulfilled
	V22	Participation in development planning processes	4.6	Fulfilled
	V23	Having authority in financial regulation	3.7	Fulfilled

There are 23 factors identified as the results of GM analysis. Further analysis was then conducted using ISM, where the initial analysis generated the Self Structural Interaction Matrix (SSIM) by merging 11 separate matrices into one. Subsequently, the SSIM matrix was converted into the Initial Reachability Matrix (IRM) by translating the contents from V, A, X, O to 1s and 0s. The application then corrected the IRM to produce the Final Reachability Matrix (FRM). This FRM was used to calculate Driver Power (DP) and Dependence (D) for each variable. Based on these values, the variables were mapped onto a four-quadrant diagram known as the Driving Power and Dependence Matrix (see Figure 3). In this matrix, 22 variables are in the Linkage Variables quadrant, which includes variables with high Driver Power and Dependence. These variables significantly influence others and require further analysis due to their overall impact. These 22 variables will affect each other, and Variable 19 (V19) is not in the same quadrant.

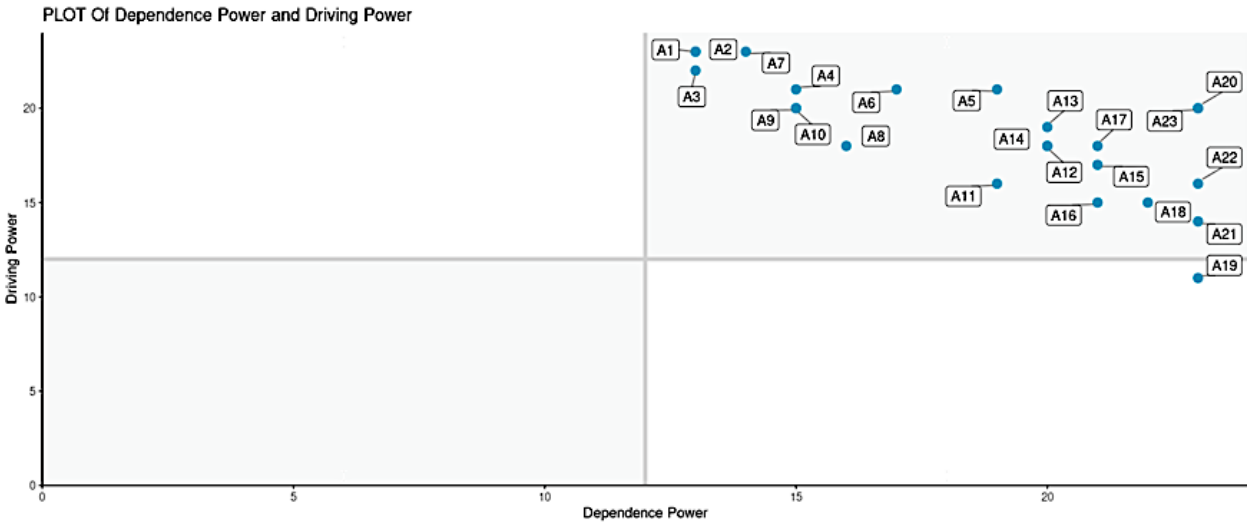

Figure 3 Driving and Dependence Power Matrix

Variable 19 (V19), "Engagement in planning activities," falls within the Dependent Variables quadrant, indicating high dependence but low driver power. This means that V19 is highly influenced by other variables. Table 3 shows the ranking for all variables established by driver power and dependence values.

Table 3 Driving and Dependence Score

Code	Driver Power	Rank	Dependency	Hierarchy
V1	23	1	13	10
V2	23	1	13	10
V3	22	2	13	10
V4	21	3	15	8
V5	21	3	19	5
V6	21	3	17	6
V7	23	1	14	9
V8	18	6	16	7
V9	20	4	15	8
V10	20	4	15	8
V11	16	8	19	5
V12	18	6	20	4
V13	19	5	20	4
V14	18	6	20	4
V15	17	7	21	3
V16	15	9	21	3
V17	18	6	21	3
V18	15	9	22	2
V19	11	11	23	1
V20	20	4	23	1
V21	14	10	23	1
V22	16	8	23	1
V23	20	4	23	1

Variables with a high dependence value will occupy hierarchy 1, whereas variables with the highest driving power value will occupy rank 1. Since dependence and driving power values represent opposite relationships, a variable with a high dependence value will have a low driving power value. Consequently, the hierarchy and ranking will also be inversely related for each variable.

Variable 19 occupies hierarchy 1 with a dependence value of 23 and ranks 11 with a driving power value of 11. Conversely, Variable 1 occupies hierarchy 10 with a dependence value of 13 and ranks 1 with a driving power value of 23. These two variables illustrate the inverse relationship: Variable 19 is highly dependent on other variables, while Variable 1 significantly influences other variables.

Based on the rank and hierarchy of the factors, a structural model of the factors can be presented. This model illustrates the level of variables based on the value of their driving power according to the results of the ISM analysis. In this model, level 1, representing the most influential variable, is at the bottom, while level 11, representing the least influential variable, is at the top. The structural model is shown in Figure 4.

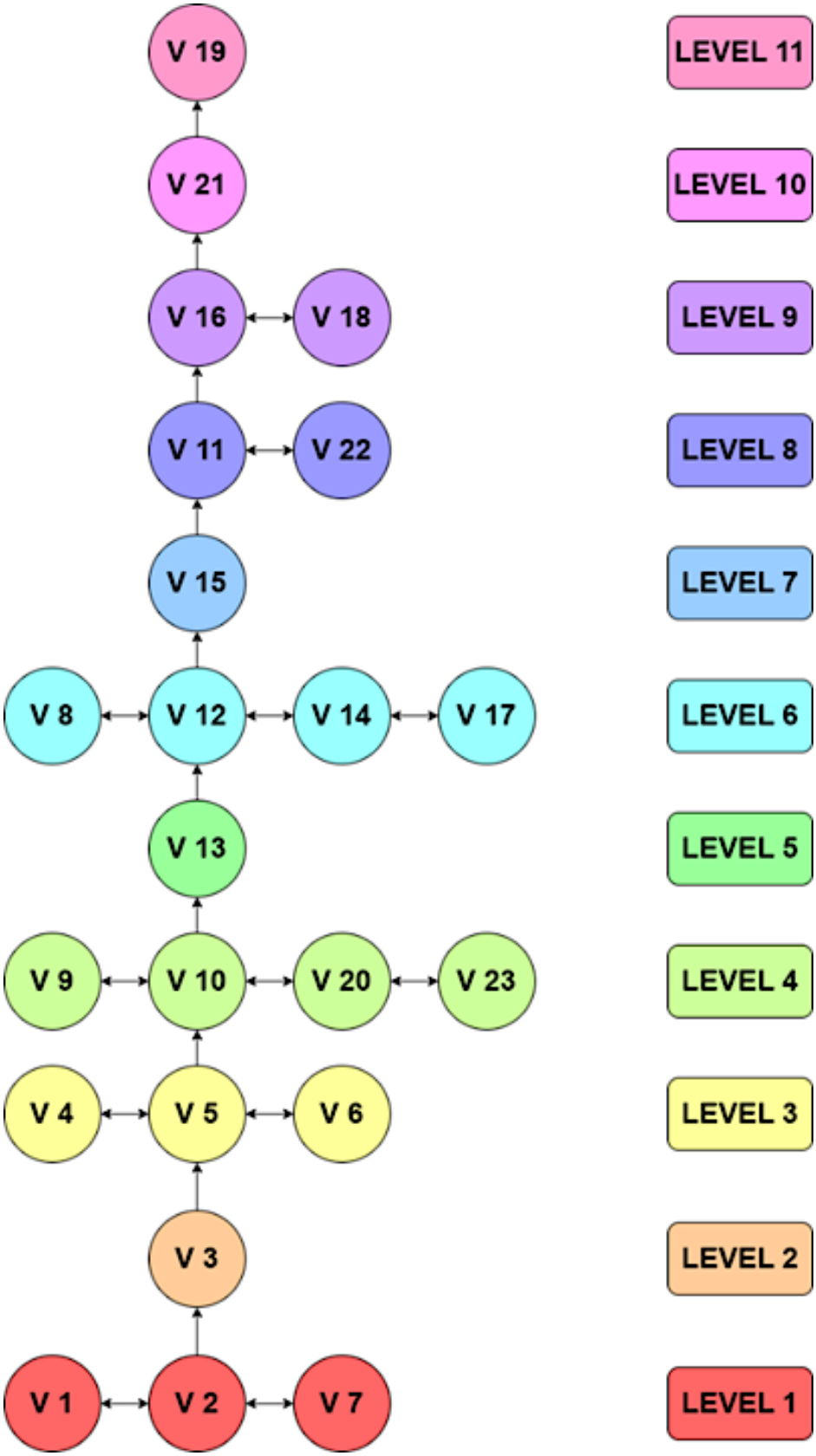

Figure 4 Structure Model of Factor

Figure 4 depicts the hierarchy or sequence of all variables that significantly influence the safe drinking water provision process. At level 1, which determines and influences subsequent factors, there are three key variables: V1, V2, and V7. On the other hand, level 11, indicating variables with insignificant influence, includes V19.

Based on the hierarchical order, these three variables are the most influential factors regarding stakeholder involvement in safe drinking water provision efforts. The first variable relates to regional autonomy and the allocation of authority between ministries/agencies. According to Law No. 9/2015 on regional autonomy, local governments manage natural resources, including clean water and sanitation. However, this authority is often not accompanied by an increase in regional capacity. Many regions still experience limited resources to implement programs that support the fulfillment of safe drinking water. (Thabroni, 2021). This issue is exacerbated by limited technical and financial assistance from the central government and other institutions or the uneven provision of assistance across regions. It can also be influenced by the differing priorities of each region, shaped by the political policy directions of regional leaders (Harirah, 2022).

The second factor is the number of stakeholders involved. Guided by Presidential Regulation No. 11 of 2022, which regulates the Roadmap for Fulfilling the 2030 SDGs Targets, various ministries and institutions are listed as stakeholders. The UN World Water Development Report 2024 emphasizes the need for partnerships across sectors to achieve the 2030 SDGs targets. A multi-stakeholder approach involving governments, international organizations, and the private sector aims to enhance the quality and speed of providing access to clean water (UN, 2024). However, this approach faces obstacles such as coordination difficulties due to the large number of stakeholders, resulting in misaligned policies and overlapping regulations that slow implementation and target achievement (Galan-Valdivieso et al., 2019).

The third factor is regulations and policies related to safe drinking water supply systems. These are fundamental and influence other factors because providing safe drinking water is a local government responsibility, yet central government policies govern procurement processes. Additionally, the physical provision of safe drinking water is challenging to segregate by region due to the continuity of river water flow, which remains the primary source of drinking water and disregards regional boundaries.

Consequently, regional interest management, typically the prerogative of regional leaders, affects political policy directions, regional cooperation, and the consistency of spatial planning documents and the Jakstrada, the Strategic Plan for Drinking Water Supply Systems. Regional leaders prioritizing safe drinking water provision will align their political policies to promote the development of safe drinking water infrastructure, accompanied by spatial planning that considers such infrastructure. If many regional leaders prioritize this, the potential for regional cooperation will undoubtedly increase. As previously elucidated, limitations on regional autonomy are a primary factor in safe drinking water provision. If regional leaders prioritize this, opportunities for collaboration with nearby regions or those sharing the same water source will emerge.

These factors will subsequently impact budgeting. Without prioritization, the allocated budget for safe drinking water provision will be minimal. If inter-regional cooperation occurs, the investment required will be lighter due to shared responsibilities. Furthermore, opportunities for utilizing other economic instruments will increase. These factors will influence cooperation between governmental and non-governmental entities, impacting stakeholder hierarchies, collaboration, and information exchange. Moreover, initiating cooperation will prompt the establishing of new regulations to support it and create opportunities for further collaboration.

5. CONCLUSION

Several key findings emerged after data collection, processing, analysis, and validation. Firstly, essential stakeholders in ensuring safe drinking water are the Ministry of National Development Planning, the Ministry of Public Works and Housing, and Local Governments. Secondly, three primary factors significantly affect the provision of safe drinking water: limitations on regional authority, stakeholder involvement, and regulatory frameworks. Thirdly, policy strategies align with these factors and emphasize the importance of stakeholder involvement.

Future research could focus on detailed stakeholder engagement plans, region-specific efforts, and exploring nuanced factors influencing safe water provision. The stakeholder mapping and structural model of the variables generated in this research highlight stakeholders' crucial role in fulfilling safe drinking water. Based on these results, further research is needed to develop comprehensive stakeholder engagement plans. Additionally, the different conditions of each region may result in varying variables and levels of stakeholder involvement. Therefore, future research should concentrate on region-specific studies to better understand these dynamics.

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INVESTIGATING THE RELATIONSHIP BETWEEN THE CONSTRUCTION SAFETY PLAN, KNOWLEDGE MANAGEMENT, AUDIT PROCESS, INFORMATION SYSTEM, WEB, AND BIM WITH CONSTRUCTION SAFETY PERFORMANCE

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ABSTRACT

The rapid growth of high-rise building construction in Indonesia has led to a significant increase in accidents, necessitating a robust audit process for construction safety. This research investigates the relationship between construction safety plans (CSPs), audit processes, knowledge management (KM), information systems, the web, and BIM on construction safety performance, aiming to develop a BIM-based KM audit process. To analyze the significance level of various indicators for each variable considerable importance, a mixed-methods approach was employed, combining qualitative insights from expert interviews with quantitative analysis using Structural Equation Modeling (SEM) via SmartPLS. The findings in the study reveal that the studied variables have a Cronbach's Alpha value above 0.7, and the retained variables have a significant value greater than or equal to 0.7. In this study, the confidence level is 95%, where there is a relationship between variables that meet the t-table, which is > 1.96, it can be concluded that the relationship between each variable has a significant value. This study provides a framework for integrating these elements to enhance construction safety performance, offering valuable guidelines for industry stakeholders to improve safety practices in construction projects.

Keywords: Construction Safety Plan, Audit Process, Knowledge Management, Information System, Web Integration, BIM, Safety Performance

1. INTRODUCTION

Indonesia has experienced significant growth in the construction of high-rise buildings, with numerous structures exceeding a height of 200 meters. Construction projects involve extensive manual labor, hence increasing the likelihood of work-related accidents. An efficient construction safety management system is necessary to mitigate the greater accident rate that is associated with increased complexity of construction. For a project to be considered successful, it must prioritize the health and safety of its workers, regardless of whether it is completed on time and under budget (Lim, 2019). The objective of implementing occupational safety and health (OSH) is to safeguard workers, company resources, the surrounding community, and the natural surroundings, as required by Law No. 1 of 1970.

The data from the Employment Social Security Institution accident insurance program in 2022 indicates an increasing yearly rise in both work accidents and occupational diseases. The number of reported accident cases in 2021 amounted to 234,370, reflecting a 5.7% rise compared to the preceding year. This data emphasizes the immediate necessity to give priority to Occupational

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Safety and Health (OSH) in the workplace to ensure the welfare of workers and the overall success of construction projects.

The implementation of construction work safety is carried out due to the risk of workplace accidents, considering the applicable standards based on the audit process regulations in the Indonesian Minister of Public Works and Public Housing No. 10 of 2021 concerning Guidelines for Construction Safety Management Systems and applicable Occupational Health and Safety (OHS) provisions. Therefore, research is needed on high-rise building projects to apply construction safety in the workplace. Implementing the construction safety management system according to regulations involves an internal audit system within construction companies to assess the level of implementation, identify influential factors, and respond with corrective actions to fulfill the Occupational Health and Safety Management System (OHSMS) and prevent work accidents (Ibrahim, 2020).

Audits are a critical component of the OHSMS, providing a means to directly and comprehensively monitor the implementation and effectiveness of the company's OHSMS (Robson, 2010). Safety audits should be conducted by personnel independent of the contractor, while safety reviews can be conducted by internal project team members. Safety audits provide fundamental proactive feedback to safety professionals and operations staff regarding deficiencies in safety management schemes (Karanikas, 2017).

To overcome safety challenges, management systems must adapt to change by effectively capturing, storing, and disseminating new injury prevention strategies. This can be achieved through the development, implementation, and maintenance of effective safety Knowledge Management (KM) processes (Hallowell, 2012). Expert auditor judgments are more accurate and demonstrate a higher level of professional scepticism in knowledge transfer and information seeking (Rodgers., et al 2017).

Safety should focus on technologies that allow construction site operators to share their knowledge and experience with planners to use BIM as a knowledge base for construction site design (John et al., 2015). Technological developments are expected to support construction applications by providing added value to each project. BIM offers efficient and optimizing benefits to the management of construction companies. Building Information Modeling (BIM) is a sophisticated technology applied in developed countries to support efficiency and effectiveness in construction company management. BIM is expected to help minimize the accident rate, especially in the construction industry (Lim, 2019).

In this research, previous studies are expanded upon with the main concept of implementing KM with an audit process integrated with BIM. Structural Equation Modelling (SEM) is a second-generation multivariate data analysis method frequently employed in research due to its ability to test theoretically supported linear and additive causal models (Haenlein & Kaplan, 2004). Analyzing the relationship between indicators can be done in several ways, including multiple regression, path analysis, factor analysis, and SEM.

SEM is a multivariate method for investigating the relationship between exogenous (independent) and endogenous (dependent) latent variables in a model simultaneously (Kline, 1998). SEM provides validity and reliability of the observed variables in the measurement model and shows the relationship between observed quantitative variables and unobserved (latent) variables (Barclay et al., 1995). Model assessment through SEM is used as a quantitative study to determine the hypothesized relationship and significance between constructs and indicators for implementation and continuation in construction. The resulting model in this study provides an objective and measurable assessment of how much construction safety performance needs to be improved throughout the project life cycle.

2. LITERATURE STUDY

In this research, the variables affecting construction safety performance are classified into six categories: construction safety plan (CSP), audit process, KM, information system, web, and Building Information Modeling (BIM). Based on this conceptualization, the following research establishes hypotheses supported by the literature to construct a Partial Least Squares-Structural Equation Modelling (PLS-SEM) model, aiming to enhance construction safety performance by integrating each influencing factor.

H1. BIM affects information systems: The use of BIM for safety in construction has the potential to increase practitioners' understanding of their site, thereby reducing the likelihood of accidents (John et al., 2015). BIM is widely seen as an enabling technology with the potential to improve communication between stakeholders, enhance the quality of information available for decision-making, improve the quality of services provided, and reduce time and costs at every stage of the construction cycle (John et al., 2015).

H2. BIM affects web: Web-based communication systems can contain safety information that can be accessed at any time, including BIM that can visualize projects and facilitate real-time communication between stakeholders, thus improving safety performance (Zou et al., 2017).

H3. KM affects information systems: KM is the process of sharing information and knowledge in the form of necessary data/documents that are always updated and accessible with information technology. Mechanisms or tools within an organization promote knowledge sharing, enabling members to improve their skills and knowledge (García-Fernández, 2015).

H4. The audit process affects KM: Developing an audit process KM information system, such as a website, assists auditors and auditees in carrying out the audit process, thereby reducing disputes in the design and build integrated contract system (Tussadiyah, 2021).

H5. The audit process affects the information system: Obtaining information related to the audit process within the organizational scope of safety performance in high-rise buildings with design contracts supports information such as rules applicable to case studies in the safety performance audit process (Dyah et al., 2023). Information systems benefit from collecting, processing, storing, analyzing, and disseminating data and information for specific purposes (Turban et al., 2008).

H6. The audit process affects the web: An audit website can provide dynamic and continuously updated information on dominant risks in the audit process, enabling wide dissemination of updated information (Tussadiyah, 2021).

H7. CSP affects BIM: Simulating safety during construction projects, the Work Breakdown Structure (WBS) can be integrated with the schedule of work implementation, including the resources used, thus providing input information to BIM (Hu & Zhang, 2011). The use of BIM for health and safety in construction can increase practitioners' understanding of their sites, reducing the likelihood of accidents (John et al., 2015). The integration of BIM and the Safety Plan should be applied throughout the project life cycle (Putra Lim & Latief, 2020).

H8. CSP affect KM: Implementing KM in buildings can improve control over critical variables related to security and safety in high-rise building projects. The knowledge map will be structured according to the specific conditions of the company and its experiences (Argiolas et al., 2022).

H9. The CSP affects the audit process: Risk control, along with safety goals and programs, are validated and can be used as a standard for developing safety goals and programs in the CSP of integrated construction work to design and build high-rise buildings. Developing standards for the SMKK audit process involves identifying the stages of the audit process, audit activities/elements, audit objectives, and potential audit risks (Akram, 2023).

H10. In the implementation of SMK3L, information systems collaborating with web applications can improve safety performance (Yufrizal, 2022). In addition to improving safety performance, using information systems can impact organizational behavior and culture, increase public collaboration, disseminate information more efficiently, and assist in decision making (Lu et al., 2014).

H11. Web affects construction safety performance: Web-based communication systems can increase involvement in construction activities by facilitating information exchange, communication links, and activities affecting safety performance indicators (Aguilar & Hewage, 2013).

The research hypotheses, shown in Figure 1, are based on the relationships between the variables of CSP, audit process, KM, information system, web, and BIM, aimed at improving construction safety performance. This is showed in the path connectivity diagram of the proposed structural relationship model to enhance construction safety performance.

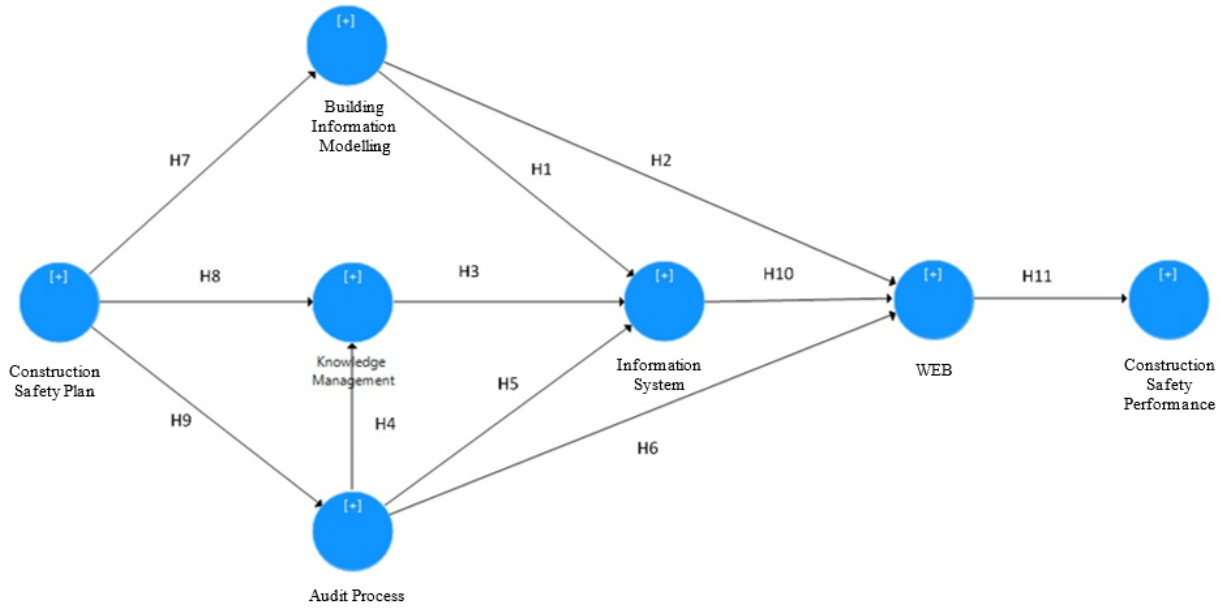

Figure 1 Research Hypothesis

3. METHODS

This study employs a mixed-method approach, integrating both quantitative and qualitative techniques to provide a comprehensive analysis of the factors influencing construction safety performance. Quantitative data were gathered through questionnaire distribution, while qualitative insights from experts were utilized to ensure a profound understanding of the presented variables. This methodological approach aims to bolster the validity and reliability of the research outcomes.

Questionnaires were distributed to experts to validate and solicit feedback from them. Expert knowledge was based on qualifications from academia or practitioners, including contractors, consultants, and government officials. Inputs from these experts were then synthesized and utilized as input for composing the questionnaire, as depicted in Table 1, which lists items considered significant to construction safety performance.

Table 1 Items Considered Significant to Construction Safety Performance

Code	Variable	Code	Variable
X1	Construction Safety Plan (CSP)	X5	Web
X1.1	Work Breakdown Structure	X5.1	WEB Content
X1.2	Hazard Identification, Risk and Opportunity Assessment	X5.2	Accuracy
		X5.3	Format
X1.3	Action Plan (Goal and Programme)	X5.4	Timeliness
X2	Audit Process	X5.5	Ease of Use
X2.1	Audit Programme Management	X5.6	Security and Privacy
X2.2	Audit Implementation	X5.7	Response and Privacy
X2.3	Audit Criteria	X6	BIM
X3	Knowledge Management (KM)	X6.1	Data Properties
X3.1	Knowledge Create	X6.2	Relationship
X3.2	Knowledge Sharing	X6.3	Utilities
X3.3	Knowledge Application	X6.4	Information Criteria
X4	Information System	X6.5	Function Criteria
X4.1	Database Planning	X6.6	Technical Criteria
X4.2	Technology Integration	X6.7	Organizational/Legal Criteria
X4.3	Technical System Integration	Y1	Construction Safety Performance
X4.4	Process Data	Y1.1	Leading Indicator
		Y1.2	Lagging Indicator

Based on the literature review, this study evaluated the relationship between CSPs, audit processes, KM, information systems, web, BIM, and construction safety performance. This evaluation involved content and construct validation of identified variables to assess the accuracy of variables, indicators, and statements. Surveys were conducted by distributing questionnaires to 63 respondents, with statistical data processed using IBM SPSS for descriptive analysis of respondent homogeneity. A data adequacy test was performed to determine significance values between variable relationships, modeling these relationships with SmartPLS 3.3.3. During data management, eight outliers were identified and excluded, resulting in 55 respondents' data being used to produce a significant relationship between variables. The stages conducted in this study which are briefly described in Figure 2.

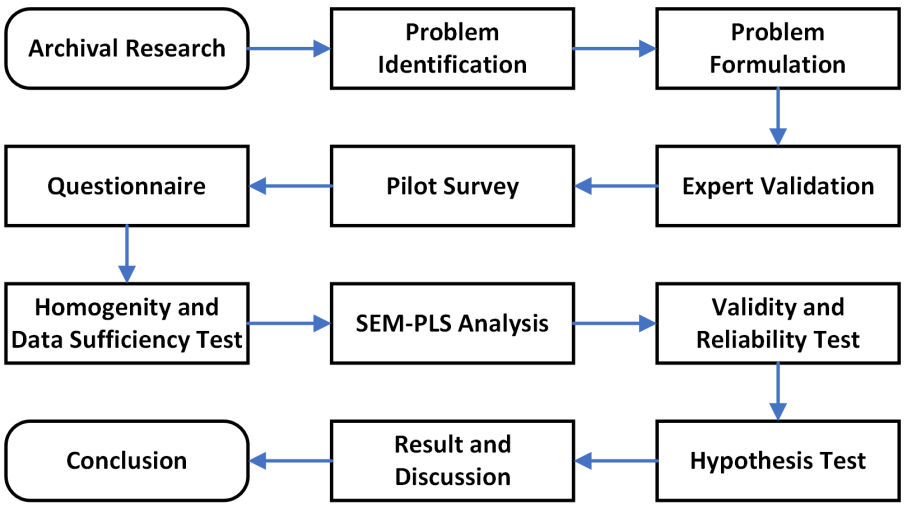

Figure 2 Research Flow

3.1. Homogeneity Test with SPSS

This study consists of seven variables with a total of 206 indicators. The homogeneity test intends to determine the level of difference in understanding the results of the questionnaire by respondents, who are influenced by several factors such as work experience, latest education, and the institution where the respondent works. The homogeneity test is a non-parametric analysis where the data variables used are nominal scales. In this study, the Kruskal-Wallis test was employed using SPSS software. The test results are considered homogeneous if the Asymp. Sig (2-tailed) is greater than the level of significance (α) 0.05 and the Kruskal-Wallis H value <0.05 (df) according to the degree of freedom value. The grouping results can be seen in Table 2.

Table 2 Respondent Grouping

No		Grouping	Number of Respondent
1	Instance	Contractor	41
		Consultant	8
		Government	4
		Academics and Practitioners	2
2	Education	Bachelor	42
		Master	12
		Doctoral	1
3	Work Experience	< 5 Years	19
		5- 10 Years	22
		> 10 Years	14

Based on the results of the homogeneity test, all indicators support the null hypothesis (H0), indicating no significant differences in respondents' perceptions based on their institution, education, and work experience. The analysis results using SPSS showed that Asymp. Sig values are greater than the level of significance, confirming the homogeneity of the data.

3.2. Data Sufficiency Test

The data sufficiency test is conducted to determine whether the data collected is sufficient based on the required number of observations (N'). Data can be considered sufficient if the number of observations made (N) is greater than the number of observations required (N'). The formula for testing the adequacy of research data is as follows:

$$N' = \left(\frac{\frac{k}{s}\sqrt{N\Sigma x^2 - (\Sigma X)^2}}{\Sigma x} \right) \quad (1)$$

If the data N' is smaller than N (i.e., 55), then the data obtained is declared sufficient. The data sufficiency test was carried out using Microsoft Excel software, and the results indicated that the data was sufficient for further data management.

3.3. PLS-SEM Analysis

SEM is a statistical technique that seeks to explain the covariance among a set of variables. SEM can be defined as a system of equations that specifies the structure of relationships between observed and unobserved (latent) quantitative variables (McQuitty and Wolf, 2013). In measurement using SEM, there are two approaches: evaluating each variable separately and testing all variables simultaneously with structural modeling.

4. RESULTS AND DISCUSSION

Relationship analysis using Smart-PLS software was conducted to estimate the causal-predictive relationships between the variables of CSP, KM, Audit Process, Information System, Web, and BIM on construction safety performance. The hypothetical model was described according to the framework shown in Figure 3.

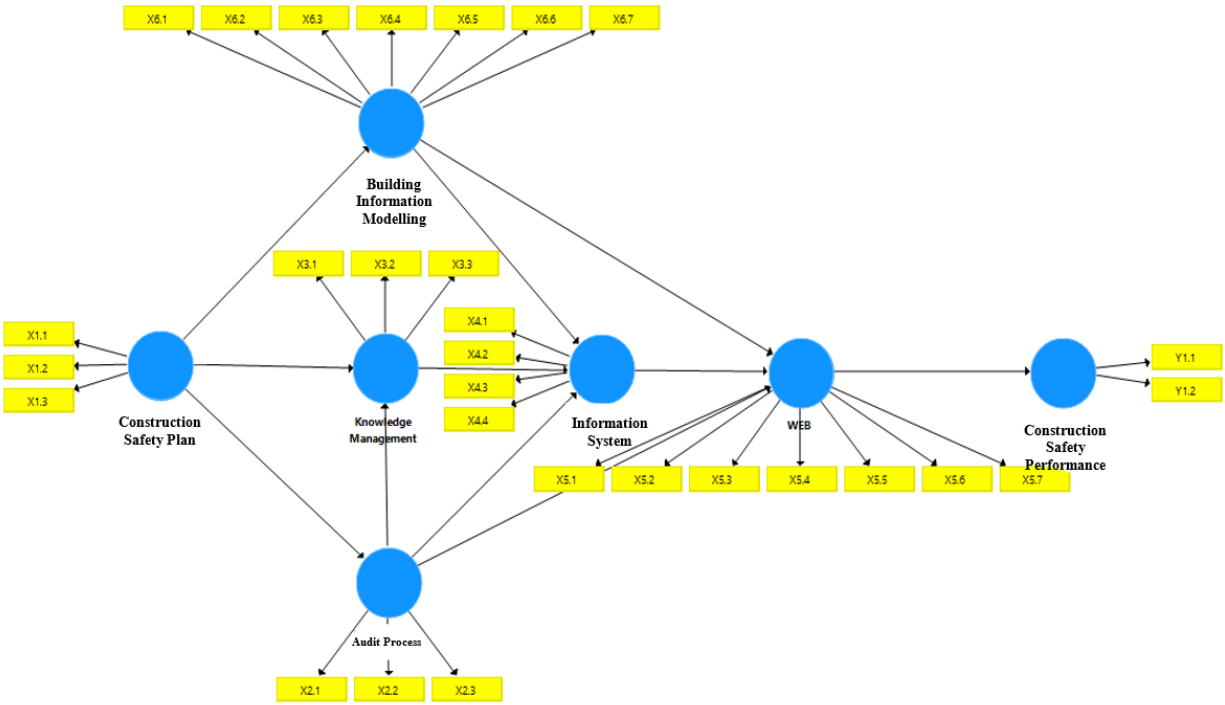

Figure 3 Research Model in Smart-PLS

4.1. Validity and Reliability Test

The validity test, based on Average Variance Extracted (AVE), aims to assess construct variables for sufficient discriminant validity and convergent validity. The standardized loading factor is a method of comparing the correlation of indicators of a construct with the correlation of indicators of other constructs. AVE is conducted as a validity test, where a variable is considered valid if the AVE value is greater than the squared correlation between the variables. A variable will be deemed valid if the AVE value is greater than 0.50 (McQuitty & Wolf, 2013).

4.1.1 Validaty Test

The loading factor value is considered to have discriminant validity if it is greater than 0.7 (Hair et al., 2013). It is necessary to check whether the AVE value of any indicator is less than 0.7, in which case it should be eliminated or retained. The AVE value of outer loadings that meet the requirement is greater than 0.7, as shown in Table 3. The validity test is performed by analyzing convergent validity according to the requirements in McQuitty & Wolf (2013) and discriminant validity according to the requirements in Hair et al. (2013). Figure 4 shows the results of the PLS algorithm calculation to determine the AVE value using SmartPLS 3.0.

Table 3 AVE Value of Outer Loadings

Variable Indicator	BIM	Construction Safety Performance	KM	Audit Process	CSP	Information System	WEB
X1.1					0,791		
X1.2					0,881		
X1.3					0,875		
X2.1				0,853			
X2.2				0,911			
X2.3				0,894			
X3.1			0,822				
X3.2			0,869				
X3.3			0,875				
X4.1						0,885	
X4.2						0,892	
X4.3						0,907	
X4.4						0,880	
X5.1							0,808
X5.2							0,765
X5.3							0,836
X5.4							0,847
X5.5							0,791
X5.6							0,717
X5.7							0,831
X6.1	0,828						
X6.2	0,832						
X6.3	0,872						
X6.4	0,894						
X6.5	0,765						
X6.6	0,865						
X6.7	0,806						
Y1.1		0,931					
Y1.2		0,914					

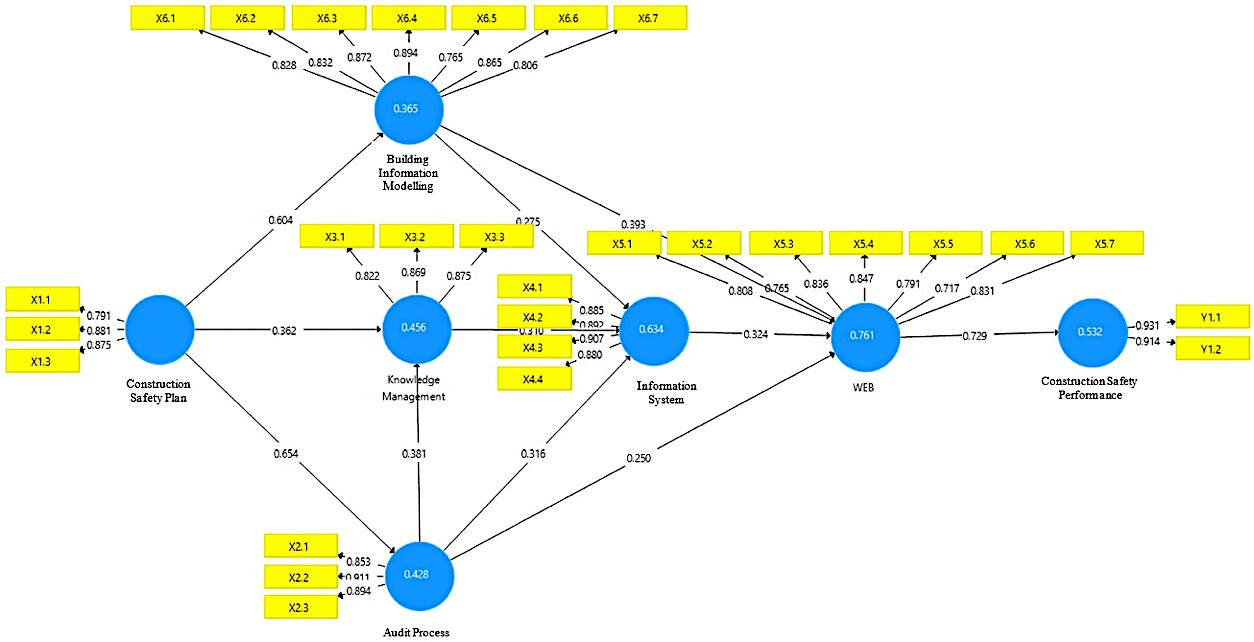

Figure 4 PLS Algorithm Calculation

4.1.2 Reliability Test

The reliability test was carried out to evaluate the outer model by assessing the reliability of the variable construct. The reliability test includes criteria such as Cronbach's alpha and composite reliability. A construct is considered reliable if the Cronbach's alpha value is greater than 0.7 and the composite reliability value is greater than 0.7. These requirements indicate the accuracy, consistency, and precision of a measuring instrument (Neuman, 2006). The composite reliability and Cronbach's alpha values for each factor were greater than 0.70, as shown in Table 4. Therefore, all factors exhibited an AVE value exceeding 0.50, indicating that the items effectively align with their respective constructs. Thus, the convergent validity of the factors is established.

Table 4 Items Considered Significant to Construction Safety Performance

Variable Indicator	Cronbach's Alpha	Composite Reliability	AVE
BIM	0,930	0,943	0,703
KM	0,826	0,920	0,851
KM	0,821	0,891	0,732
Audit Process	0,864	0,917	0,786
CSP	0,809	0,886	0,723
Information System	0,913	0,939	0,793
WEB	0,906	0,926	0,641

The AVE value for each variable exceeds 0.5, indicating that the construct has valid data. Additionally, the Cronbach's alpha value for each construct is greater than 0.7, and the composite reliability value for each construct is also greater than 0.7. Therefore, it can be concluded that all constructs are both valid and reliable.

4.2. Hypothesis Test

Hypothesis testing is conducted by examining the path coefficient value, which indicates the parameter coefficient and the t-statistic value. If the t-statistic value is greater than the t-table value, then the hypothesis is accepted. In this study, the confidence level is 95%, so the t-table value for the one-tailed hypothesis is 1.96. For example, the relationship between the CSP and the Audit Process has a t-statistic value of 3.305. This means that the t-statistic is greater than the t-table value (3.305 > 1.96), indicating that the relationship between the CSP and the Audit Process is significant. The path coefficient results are shown in Figure 5 and Table 5.

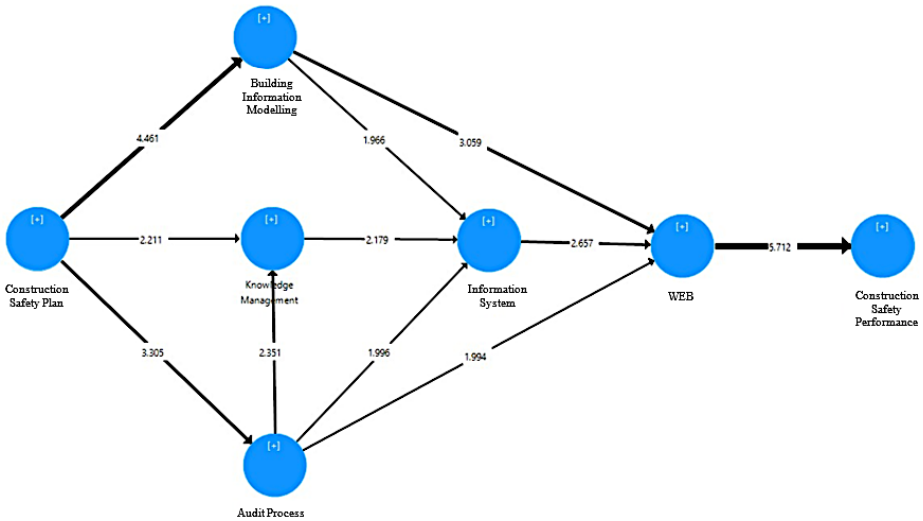

Figure 5 Effect of Relationship between Variables

Table 5 shows that there is a relationship between variables that meet the t-table criteria for significance, namely where the t-statistic value is greater than the t-table value.

Table 5 Path Coefficient Results

Relationship between Variables	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
BIM → Information System	0,275	0,278	0,140	1,966	0,025
BIM → Web	0,393	0,389	0,128	3,059	0,001
KM → Information Systems	0,310	0,313	0,142	2,179	0,015
Audit Process → KM	0,381	0,360	0,162	2,351	0,010
Audit Process → Information System	0,316	0,301	0,159	1,996	0,023
Audit Process → Web	0,250	0,264	0,125	1,994	0,023
CSP → BIM	0,604	0,594	0,135	4,461	0,000
CSP → KM	0,362	0,367	0,164	2,211	0,014
CSP → Audit Process	0,654	0,608	0,198	3,305	0,001
Information System → WEB	0,324	0,310	0,122	2,657	0,004
Web → Construction Safety Performance	0,729	0,714	0,128	5,712	0,000

Path modeling in PLS-SEM first examines the direct effects between variables. Subsequent analysis determines the indirect effects mediated by other variables (Shanmugapriya & Subramanian, 2016). The total effect is then calculated by summing the direct and indirect effects, providing a comprehensive understanding of the model structure relationships (Nitzl et al., 2016). The results of the total effect analysis using PLS-SEM are presented in Table 6.

Table 6 Total Effect Results

Relationship between Variables	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
BIM → Construction Safety Performance	0,351	0,341	0,109	3,224	0,001
BIM → Information System	0,275	0,278	0,140	1,966	0,025
BIM → Web	0,482	0,478	0,124	3,896	0,000
KM → Construction Safety Performance	0,073	0,069	0,047	1,558	0,060
KM→ Information Systems	0,310	0,313	0,142	2,179	0,015
KM → Web	0,100	0,094	0,057	1,751	0,040
Audit Process → Construction Safety Performance	0,285	0,281	0,111	2,569	0,005
Audit Process → KM	0,381	0,360	0,162	2,351	0,010
Audit Process → Information System	0,434	0,415	0,149	2,921	0,002
Audit Process → Web	0,391	0,392	0,135	2,895	0,002
CSP → BIM	0,604	0,594	0,135	4,461	0,000
CSP → Construction Safety Performance	0,425	0,418	0,161	2,643	0,004
CSP → KM	0,611	0,595	0,162	3,770	0,000
CSP → Audit Process	0,654	0,608	0,198	3,305	0,001
CSP → Information System	0,562	0,556	0,158	3,549	0,000
CSP → Web	0,583	0,567	0,154	3,791	0,000
Information System → Construction Safety Performance	0,236	0,225	0,104	2,275	0,012
Information System → Web	0,324	0,310	0,122	2,657	0,004
WEB -> Construction Safety Performance	0,729	0,714	0,128	5,712	0,000

The results presented in Table 6 demonstrate that the path coefficient and total effect values meet the criterion of a t-statistic value greater than 1.96, indicating positive and significant influences between the variables. Path analysis of the resulting model reveals two primary paths encompassing all variables:

1. CSP →Audit Process → KM → Information System → Web → Construction Safety Performance (Y1 = 0.654X1 + 0.381X2 + 0.310X3 + 0.324X4 + 0.729X5)
2. CSP → BIM → Information System → Web → Construction Safety Performance (Y2 = 0.604X1 + 0.275X6 + 0.324X4 + 0.236X5)

The regression equations Y1 and Y2 illustrate the relationships between the dependent variables (Y1 and Y2) and the independent variables. The coefficients indicate how a one-unit change in an independent variable affects the dependent variable, assuming other variables remain constant. For example, a one-unit increase in X1 leads to a 0.654 unit increase in Y1, while a one-unit increase in X5 results in a 0.729 unit increase in Y1. Similarly, a one-unit increase in X1 leads to a 0.604 unit increase in Y2, while a one-unit increase in X5 results in a 0.236 unit increase in Y2. These equations enable the prediction of Y1 and Y2 values based on the independent variable values, providing insights into the relationships among variables within the regression model.

In addition to identifying dominant indicators, the results of data analysis produce a relationship model between variables. The coefficient value affects the predictive nature of the independent variable on the dependent variable, as seen in the original sample column (O). It is interpreted that the CSP influences construction safety performance based on previous literature. The development of risk control standards, along with safety goals and programs in the CSP, identification of work activities at the WBS level, potential hazards and risks, and risk control can improve construction safety performance, as referenced in the regulation of the Minister of Public Works and Public Housing No. 10 of 2021 (Akram, 2023).

This research employed a questionnaire methodology to acquire data, with the questionnaire distributed based on predefined criteria. These criteria included the institution, years of experience, and the highest level of education attained. The study demonstrates that web integration stands out as the most significant factor in enhancing construction safety performance. Additionally, five other factors, including CSP, audit processes, KM, information systems, and BIM, exert considerable influence on improving construction safety performance. The factors affecting safety performance were assessed through PLS-SEM, with the resulting values falling within parameter boundaries. Therefore, the hypotheses generated in this study have been proven.

Referring to the t-statistic values and p-values from the PLS-SEM results, the variable "web" demonstrates the highest level of significance in influence. The cross-loading results on the outer loading indicators also show a positive impact on the "web" variable. Therefore, this study recommends that auditors implement and enhance construction safety performance by integrating the web as the information system platform containing an open database of variables for exchange and phased realization transmission online, as well as for the observation and control of audit activities, with other variables serving as support, as all presented variables are interconnected.

The results of experts' validation are synergistically supported by previous research emphasizing the importance of developing CSPs to enhance construction safety performance. Improving construction safety performance can be attained through the incorporation of risk management measures, identification of root causes, and establishment of objectives and programs within the CSP. Integrating these elements with an information system aligns with the guidelines outlined in the Minister of Public Works and Public Housing Regulation Number 10 of 2021 (Rahma, 2023). The audit process is an important element of the OHS management system because audit activities are carried out to review and evaluate the performance and effectiveness of the

applicable OHS management system (Robson, 2010). The application of KM in buildings can improve control over critical variables in security and safety in high-rise building projects. The knowledge map will be structured according to the specific conditions of the company according to the experience that the company has gone through (Argiolas et al., 2022). Information systems facilitate tracking records of incidents, conditions, and dangerous behavior, processing data into various forms of needed information, and allowing direct access by interested parties to improve construction safety (Yufrizal, 2022). Web-based information systems can increase involvement in construction activities by facilitating information exchange, communication links, and activities that affect safety performance indicators (Aguilar & Hewage, 2013). The use of Building Information Modelling (BIM) for health and safety on construction sites has the potential to increase practitioners' understanding of their sites, thus reducing the likelihood of accidents (John et al., 2015).

From the relationship analysis results, a new theory is derived in this study. Theory is a collection of concepts, definitions, propositions, and variables that are systematically related and have been generalized to explain and predict certain phenomena (Cooper & Emory, 1995). The new theory derived from the relationship model explains the equations of Y1 and Y2 values based on the independent variable values and provides an understanding of the relationships among the variables within the regression model. The implementation of BIM in the occupational safety management system can elevate the level of workplace safety and pinpoint potential hazards that may arise during the initial planning, construction, and maintenance stages of construction projects (Lim, 2019).

5. CONCLUSION

This study identifies key factors influencing the audit process to enhance construction safety performance. The dependent variables Y1 and Y2 are influenced by multiple independent variables. For Y1, CSPs, audit processes, KM, information systems, and the web significantly contribute to its outcome, with the web demonstrating the highest impact. Conversely, for Y2, CSPs, information systems, the web, and BIM play notable roles. These results underscore the intricate relationships between the independent variables and the dependent variables Y1 and Y2.

Such insights are essential for understanding the underlying dynamics of the phenomena under investigation and can offer valuable guidance for decision-making processes in relevant domains. Specifically, BIM significantly impacts the evaluation of construction safety implementation. Therefore, auditees are advised to focus on these factors when implementing the audited process, which has been validated by experts in this study.

Recommended strategies include implementing CSPs and integrating them with BIM modeling, supported by a web-based information system for quick online adoption and access, to enhance construction safety performance. Further research should aim to identify additional factors that can improve construction safety performance.

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EMPOWERMENT OF INCREASING ECONOMIC RESILIENCE POST COVID-19 JANJANG WULUNG VILLAGE COMMUNITY THROUGH CREATIVE ECONOMIC VILLAGE PLANNING

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ABSTRACT

Janjang Wulung Village is one of seven villages located at a highland of 593.73 meters above sea level in Puspo District, Pasuruan Regency, East Java. Janjang Wulung Village has natural resource potential from coffee, apples, avocados, and forest products supported by the plantation area, reaching 280.1 and farmers of 1,072 people. The livestock sector is also one of the superior productions in Janjang Wulung Village, with each household having 3-6 dairy cattle with a population of 602 people who work as breeders. However, the condition of COVID-19 limiting social activities resulted in a 20% to 40% decrease in income. So, planning the development of Janjang Wulung Village as a creative economy village is necessary to create an economically resilient village. Four analyses are used, including problem trees, analysis of village and community resilience, and SWOT, followed by the analysis of project alternatives that are resulting projects. The project includes village physical resilience, such as road rehabilitation projects, clean water system development projects, procurement projects, Wi-Fi Corner, food diversification innovation projects, technology development projects, and modules and poster projects using technology to support the development of the creative economy.

Keywords: Economic Risilience; Creative Economy; COVID-19

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1. INTRODUCTION

Janjang Wulung Village is divided into five hamlets, namely Kopek Hamlet, Krajan Hamlet, Sembung Hamlet, Lasgung Hamlet, and Delik Hamlet. The creative economy development economy in Janjang Wulung Village can be implemented by assessing the potential and problems. Exploring the potential found, several prospects come from aspects of nature, economy, forest products, agriculture, plantations, and institutions. Prospects at Janjang Wulud are found in food crops and plantation commodities, where the largest food crop production is corn, which amounts to 20,744 tons per year, and for plantations, the largest production is cotton kapok with 352.24 tons per year (BPS, 2020).

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However, problems in Janjang Wulung Village are still found, such as road infrastructure problems using macadam pavement along 19.4 kilometers (km), making it difficult for road users to pass through due to jagged rocks and plains whose elevation is quite steep. The difficulty in getting clean water is also still found even though there is clean water from Umbulan in Dusun Lasgung.

Still, the location in the lowland makes it difficult for the water to flow throughout the village (Survei Sekunder, 2020). In addition, problems related to the COVID-19 Pandemic have made three sub-districts in Pasuruan Regency the Coronavirus red zone, including the Puspo District (Emil, 2020).

Janjang Wulung Village has prevented and handled the COVID-19 virus byass spraying disinfectants on May 1, 2020, as a form of activity for the resilience of the village and village communities (Hidayat, 2020). There are ways to overcome the economic problems currently occurring due to the Pandemic by developing the creative economy through 17 sub-sectors that have been defined and prioritizing local wisdom. All regions in Indonesia, including Janjang Wulung Village, are prioritized as an example of creative economic resilience villages, Puspo District, Pasuruan Regency, East Java are p (Kementrian Pariwisata dan Ekonomi Kreatif, 2020). A creative economy is the development of concepts based on creative assets that have the potential to increase economic growth (Sopanah, Bahri, & Ghozali, 2018). According to the Law of the Republic of Indonesia Article 1 of 2015, the creative economy embodies of added value from an idea or ideas that contain authenticity, emerging from human intellectual creativity based on science, skills, and cultural heritage intellectual property technology. The main elements of the creative industry are creativity, expertise, and talents that have the potential to improve welfare by offering intellectual creations (Rakib et al., 2018).

Human resources determine the empowerment of potential assets, namely, how the community can be skilled at empowering this potential to produce tradeable products (Mayasari & Chandra, 2020). Community empowerment creates a community with much greater control over its environment and the process development of organizational means (Badaruddin, 2020). Assessment in terms of community empowerment is part of the development paradigm that focuses on all the principal aspects of humans in their environment, starting from the intellectual aspect (Human Resources), material and physical aspects, to managerial elements. These aspects can be developed into sociocultural, economic, political, security, and environmental factors (Cristina, 2020). However, there are still problems in implementing empowerment, especially from human resources. The limited means of communication and information cause the public not to know the surrounding environment (Hansson, et al., 2020). So, learning or training is needed regarding knowledge, skills, and attitudes to create independent business opportunities and independence from other parties.

Janjang Wulung Village has both potential and problems. Therefore, a study was conducted that aims to find out how the physical and non-physical conditions of Janjang Wulung Village to examine the resilience of the Janjang Wulung Village community in the COVID-19 Pandemic through the excavation of the leading sector and prepare development directions for Janjang Wulung Village to develop the creative economy during and after the Pandemic. The discourse networking analysis method is expected to systematically identify a discourse relation in various documents to form a complex network. Participatory Rural Appraisal (PRA) and Rapid Rural Appraisal (RRA) are used in this data collection.

2. RESEARCH METHODS

The research method is divided into two. First, a data collection method combines primary and secondary data obtained online. Second, there is a data analysis technique using village and

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community resilience analysis as the focus on consideration analysis for planning direction by the resilience condition of Janjang Wulung Village.

2.1. Data Collection

This study uses the online primary and secondary data collection methods which Discourse Networking Analysis analyzes. Discourse Networking Analysis is a technique for visualizing political and sociocultural discourses into a network that allows us to systematically identify a discourse structure in various textual documents such as newspaper articles, print media,r transcripts of debates in parliament (Pratama & Ulfa, 2017). This Discourse Networking Analysis method combines secondary data from PRA (Participatory Rural Appraisal) and primary RRA (Rapid Rural Appraisal) data.

Participatory Rural Appraisal (PRA) is an exercise for communication and transfer of knowledge that gather/collects information by the involvement of Rural/local communities for decision-making and implementation of the development project "for the rural community, by the rural community and with the Rural Community (Arthika, 2020). With the results of PRA, the community will undoubtedly provide potential in themselves. Through this potential, the community can develop the village's potential according to its potential (Harani, 2017). The community-based approach was also chosen because village development in Indonesia is based on community-based development, so existing planning is right on target (Andari, 2019). The PRA was implemented using primary data from the 2018 PRA result and integrated the data received with online interviews due to the Pandemic that led to limited access.

2.2. Data Analysis

The analytical technique used in this research is the analysis of village and community resilience. This analysis of village and community resilience aims to determine the physical and non-physical conditions of Janjang Wulung Village to determine the direction of further development from the consideration of resilience analysis. Resilience is the dynamic condition of an area that includes all dimensions of life that can develop and be integrated into the face of threats, challenges, and obstacles (Mardhani, Runturambi, & Hanita, 2020). Community resilience is a crucial concept of resilience a region or region possesses. Society is a group of people living with all their cultures and personalities (Purwaningsih, 2020). However, it is necessary to use other PRA tools and supporting analysis from this analysis.

The PRA tool to support village and community resilience analysis data uses eight crosschecked PRA data (Comparison of 2018 and 2020 data) consisting of village mapping, village transects, village history flows, Venn diagrams, livelihood studies, input and output flow charts, season calendar, and ranking chart which then identified the problem to find out the leading causes of creative economy development in Janjang Wulung Village by using problem tree analysis. Problem tree analysis is a step in solving a problem by looking for the reason an effect (Asmoko, 2019).

Apart from the problem tree analysis for the PRA Tool, this study also uses other supporting data analysis techniques starting from the ability and land suitability analysis, analysis of settlement facilities and infrastructure, settlement analysis, population analysis, economic income analysis, and policy analysis. After all analysis data has been collected, all PRA and other analytical data are analyzed in the analysis of village and community resilience. In addition, there is also potential and problem analysis, root cause analysis, root purpose analysis, and SWOT analysis, which can be seen in the analytical framework in Figure 1.

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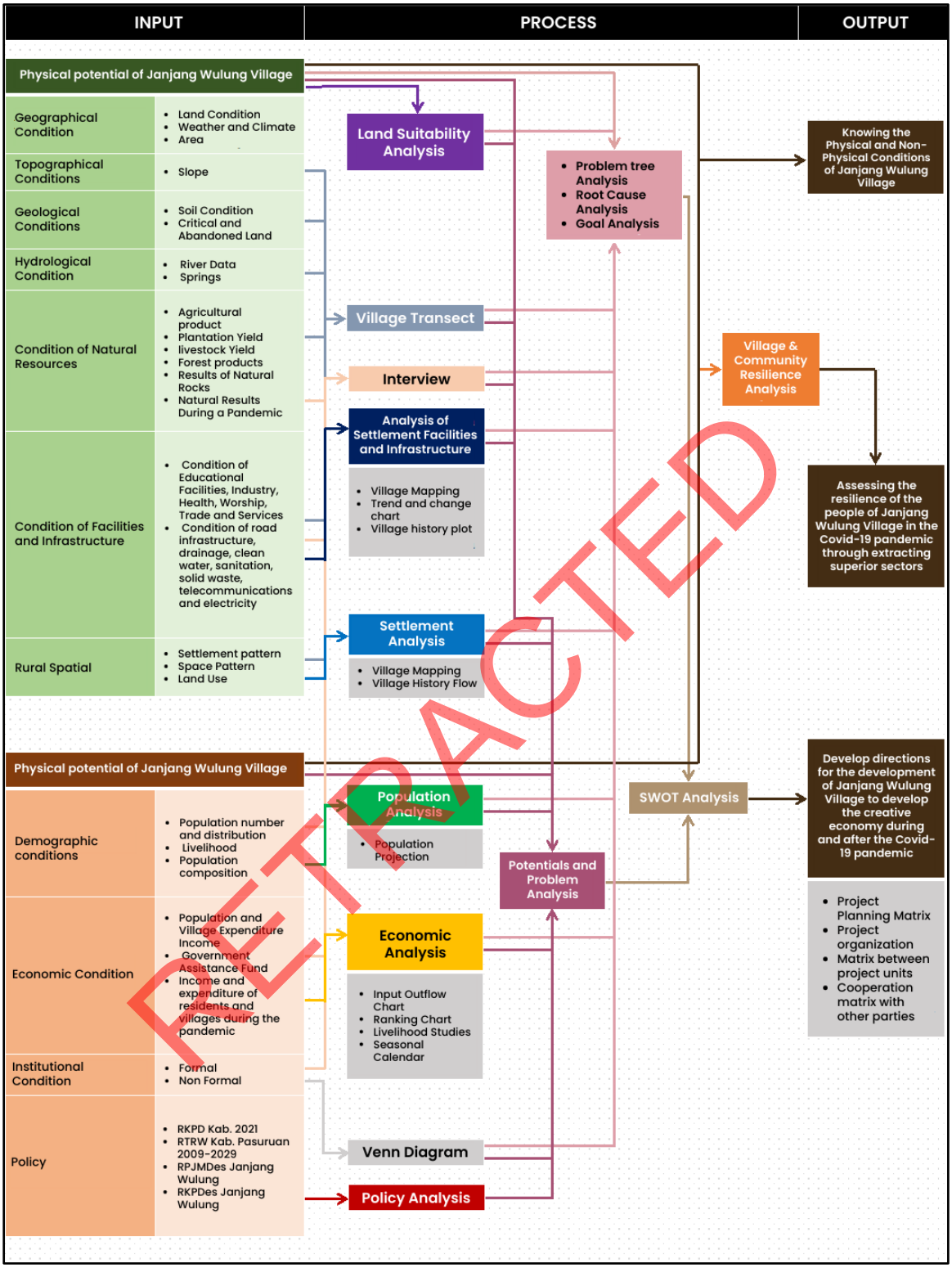

Figure 1 Analysis Framework

3. RESULTS AND DISCUSSION

Janjang Wulung Village is one of seven villages in Puspo District, Pasuruan Regency. The area of Jajang Wulung Village is 7 km2 (14.46% of the total area of Puspo District), with a high population density of 599 people/sqm (see Figure 2). It consists of 5 hamlets: Krajan Hamlet, Lasgung Hamlet, Sembung Hamlet, Kopek Hamlet, and Dusun Delik, 6 Rukun Warga (RW), and 20 Rukun Tetangga (RT). Janjang Wulung Village, located in the Pasuruan Regency area, has a very strategic location because it is a crossroads from Surabaya – Malang, Surabaya – Probolinggo, and from Probolinggo to Malang through the Pasuruan Regency area.

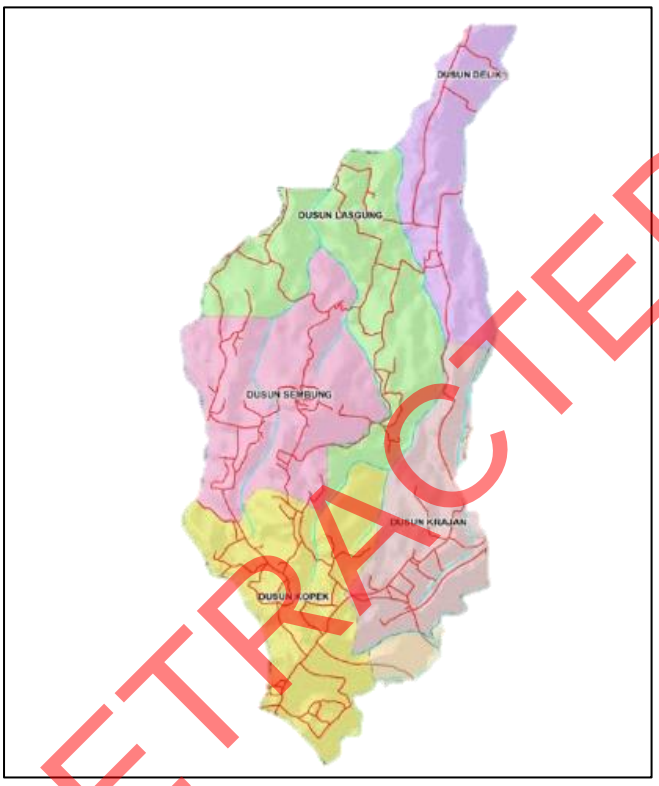

Figure 2 Janjang Wulung Village Administration

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Janjang Wulung Village is located at an altitude of 593.73 meters above sea level and in a mountainous area. Therefore, Janjang Wulung Village is included in the highland area. In addition, Janjang Wulung Village has the same slope as Pasuruan Regency and Puspo District, which has a slope between 0-2% (Pasuruan Goverment, 2020). Janjang Wulung Village only has 1 type of soil, namely Andosol soil, so Janjang Wulung Village is included in the medium fertile area with a land area of 261 ha with moderate fertility. The level of erosion in Janjang Wulung Village is relatively light, with an area of only 10 ha, a depth of around 50-99 cm with an area of 218.73 ha, and Janjang Wulung Village has a critical land of 20 ha, which is classified as low.

3.1. Trouble Tree

The analysis results using a problem tree produce details of the cause of an effect which can then be used as a solution to a problem. In addition, this analysis also illustrates the correlation between the problem, the cause of the problem, and the effect of a problem in a hierarchy of interrelated factors (Prayitno, et al., 2022). The following are the results of the problem tree analysis in Janjang Wulung Village (see Figure 3).

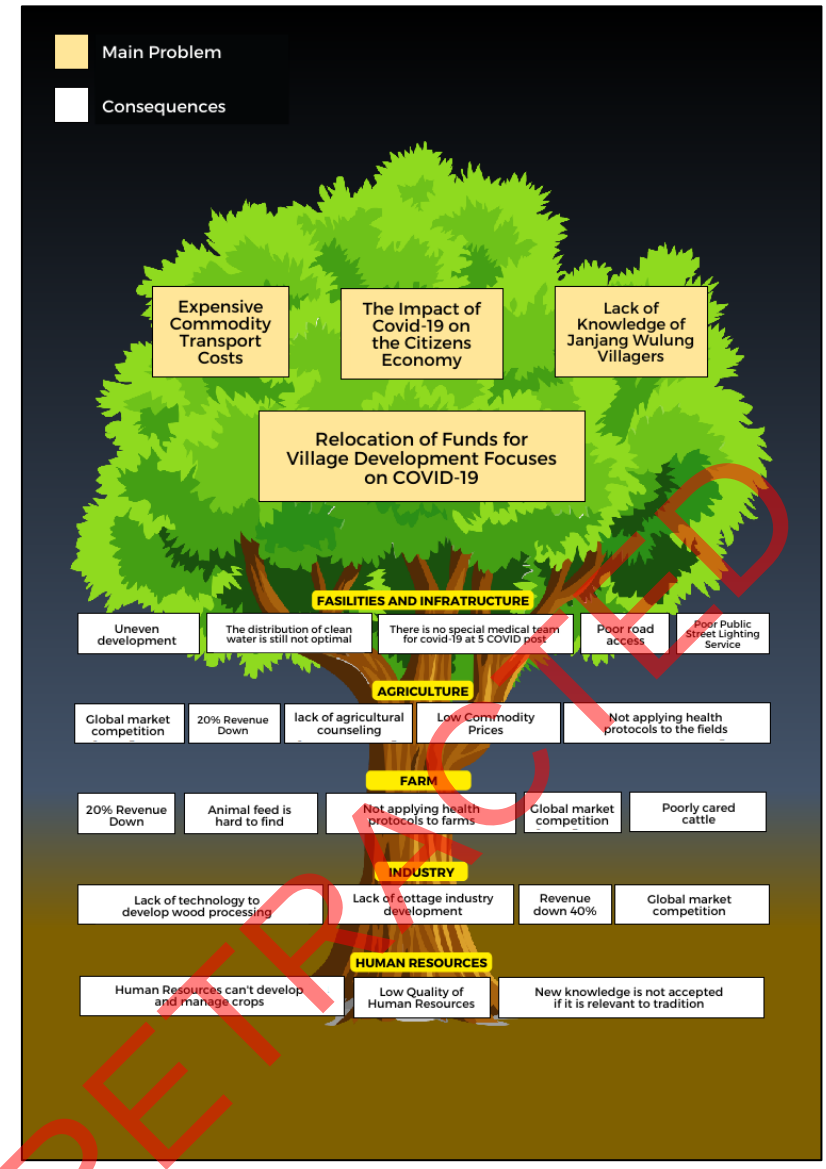

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Figure 3 Problem Tree

As seen in the picture, it can be concluded that there is a bad influence or impact from the Pandemic on agriculture, which has resulted in residents having to adjust their needs more than before the Pandemic with farm wages that have not changed. In addition, compared to conditions in 2018, the cattle owned by the residents, which initially numbered 6 heads, were reduced to 3 cows. This is because it is increasingly difficult to get animal feed, so livestock are less well cared. It can also be concluded from all the existing problems that impact citizens' income or the economy slowly.

3.2 Analysis of Village and Community Resilience

Analysis of the village and community resilience is seen from six essential criteria and seven components of assessing existing conditions. The weighting is also based on the six criteria, with one (1) point for each measure if it is appropriate and zero (0) if it is not warranted.

Table 1 Per-indicator Criteria Score

No	Criteria	Information	Score
1.	*Equity*	Guarantee of human rights regardless of background	1
2.	*Quality*	There are services and availability of quality basic materials such as food, clean water, health services, and affordability of transportation	1
3.	*Ecology*	Use of natural resources wisely for now and in the future	1
4.	*Ownership*	Main control of existing resources	1
5.	*Diversity*	Protect and respect cultural diversity	1
6.	*Self-reliance*	Providing and sharing needs in an emergency	1
Total Per-Component Assessment of Village and Community Resilience Analysis			**6**

The essential criteria are Equity, Quality, Ecology, Ownership, Diversity, and Self-Reliance (Surjono et al., 2019). In addition, the assessment components used to assess the condition are divided into local knowledge, community networks and relationships, preparedness, health, resources, governance/leadership, and economic investment. In addition, a Likert scale is also used to assess the resilience of the Janjang Wulung Village and Community.

Table 2 Defensive category determinant assessment

No	Category	Weighting Value
1.	Hold High	26–34
2.	Medium Endurance	13–25
3.	Survive Less	1-12

After the analysis, it was found that Janjang Wulung Village could survive but not optimally, with a total weighting value of 22. This happens because many people in Janjang Wulung Village still have not implemented health protocols properly even though 90% of the residents already know the danger of the spread of the COVID-19 virus, and the assistance provided by the government cannot be felt by all citizens. After all, it is only given to the poor. In addition, it can also be concluded that from residents and villages.

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3.3. SWOT Analysis

SWOT is a strategic planning and management tool to build organizational and competitive strategies (Gurel, 2017). The SWOT analysis uses a strategic planning framework that has 2 dimensions internal dimension (weakness and strengths) and also external dimension (opportunities and threats) (Benzaghta et al., 2021). SWOT analysis will produce the best recommendation related to the needs of the client/community, so this analysis will be more targeted and effectively implemented (Groseli, 2015). The identified aspects are divided into internal issues and external issues, which will later be combined to find alternatives to solving threats and weaknesses. The following is a combination or combination of internal and external problems in Janjang Wulung Village.

Table 3 SWOT Analysis Results

Internal / External	S (Strength)	W (Weakness)
	• Janjang village is located in the highlands with good slope stability and fertile andosol soil types for farming. • Good physical condition and scale of service facilities so that they can serve the community • There are COVID-19 Command Posts throughout the village • The drainage network is adequate to drain runoff water and household wastewater • The people of Janjang Wulung Village already have a semi-permanent and non-permanent housing system • The commodities of cassava, bamboo, cloves, durian, and avocado are favorites commodities in Janjang Wulung Village • Abundant cow's milk production • The existence of KUD improves the economy of the villagers • The number of residents scattered throughout the hamlet and the relatively low population growth	• Janjangwulung Village is dominated by high erosion rates with relatively low rainfall • Uneven distribution of facilities • The condition of the road pavement is macadam which makes it challenging to distribute livestock products • Clean water infrastructure is complicated in some hamlets because they still rely on springs from other villages and are obtained in rotation • There are deposits in some drainage channels • Villagers do not accept forms of counseling that are not by tradition • The condition of the road pavement is macadam which makes it challenging to distribute livestock products • Difficult to get feed for livestock • Unequal distribution of population, the lowest population of Dusun Lasgung with the most significant area • The influence given by several institutions is not so great and can be felt by the community
O (Opportunity)	**SO**	**WO**
• The existence of the Pasuruan Regency RTRW policy for 2009-2029 regarding road development has been carried out in Janjang Wulung Village through the construction of road pavements that were previously ground into asphalt and macadam to improve the quality of infrastructure and facilitate transportation of villagers and the addition of the electricity network by establishing a JTM • The existence of the MUSREMBANGDES policy with the construction of communal toilets in Krajan and Kopek hamlets, submission of montong durian seedlings in Sembung and Lasgung hamlets, and construction of public street lighting • There is assistance from the government and Nestle in the care of livestock	• There is a MUSREMBANGDes policy related to developing facilities and infrastructure to improve the quality of existing facilities and infrastructure more optimally than their conditions and services. One is related to sanitation infrastructure with details in the form of building communal toilets in Krajan and Kopek hamlets. • The Pasuruan Regency RTRW 2009-2029 policy regarding road development as the basis for carrying out road repairs to support the existence of KUD to increase the economic improvement of the residents of Janjang Wulung Village. • The Pasuruan Regency RTRW 2009-2029 policy regarding road development as the basis for road repairs to support the distribution of favorite agricultural commodities outside the hamlet and outside the village of Janjang Wulung. • There is assistance from the government and Nestle in livestock care as a basis for increasing animal feed and abundant cow's milk production. • The existence of assistance from the government and Nestle will help increase livestock products.	• There is assistance from the government and Nestle to improve the quality of livestock commodities through counseling due to the poor quality of cattle due to the difficulty of finding animal feed. • The existence of assistance from the government and Nestle in livestock care will improve the quality of commodities and villagers through direct outreach. • The Pasuruan Regency RTRW 2009-2029 road development policy can improve the road pavement's condition, which is still in the form of macadam, to distribute livestock products better. • The Pasuruan Regency RTRW 2009-2029 policy regarding road development facilitates accessibility in the level of service facilities that are still not evenly distributed. • A policy in the RTRW of Pasuruan Regency 2009-2029 regarding improving facilities and infrastructure will help solve the problem of unequal facilities and infrastructure problems, such as clean water.

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T (Threats)	ST	WT
• Lack of support from the government • The selling price of agricultural, livestock, and forest products is low due to the difficulty of marketing during the Pandemic	• Using soil fertility in Janjang Wulung Village for good agricultural management will reduce the threat of the lack of government support for the farming sector. • Good management of only commodities such as cassava, bamboo, cloves, durian, and avocado will minimize the threat from the difficulty of commodity marketing during this Pandemic. • Improving the quality of service and the physical condition of the facilities will eliminate the threat of the lack of government support for the shape of the existing facilities in Janjang Wulung Village. • The management of the COVID-19 Command Post and Polindes health facilities will minimize the threat from the government that does not support the condition of health facilities. • The existence of KUD, which helps the production of cow's milk which is relatively abundant, can improve the economy of farmers despite the threat of difficult marketing in this Pandemic.	• The uneven distribution of facilities can be minimized by building and rehabilitating facilities to avoid threats from the lack of government support for the condition of facilities in Janjang Wulung Village. • Improving the quality of accessibility can reduce the weakness of residents who have difficulty distributing milk from cows whose rate has decreased due to wobbling on the roads to avoid threats from the lack of government support for the existing road network in Janjang Wulung Village. • The development of the quality of livestock activities in animal feed technology processing can minimize farmers' difficulty obtaining animal feed to avoid the lack of government support for the livestock sector. • The development of the Clean Water Network can minimize the difficulty of clean water infrastructure due to the condition of the topography of Janjang Wulung Village which is getting higher and higher so that several hamlets at an altitude still have to get clean water in rotation. • Training on relevant technology can overcome the knowledge of the residents of Janjang Wulung Village who cannot accept new insights, especially in the use of natural resources if they are not relevant to existing traditions to avoid marketing difficulties for superior commodities in this Pandemic. • Improving institutional performance can increase institutional influence on the people of Janjang Wulung Village which currently does not have much effect on the utilization of human resources, this can also be a strategy to avoid threats from the lack of government support for institutional influences.

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3.4. Development Concept

Janjang Wulung Village has a low community welfare condition because the fulfillment of the economic and social needs of the community is still not optimal. In meeting financial requirements, most people with a livelihood in the agricultural and livestock sectors still need help marketing each sector's commodity products. This is because the road infrastructure is not in good condition. There is a steep road terrain, damage to several sections, and a lack of completeness of the road, so residents have difficulty doing marketing. The condition of road infrastructure like this causes difficulties in the process of using the mode of transportation so that when it reaches the market, the selling price of the results will be low.

The people of Janjang Wulung Village are still not optimal in meeting social needs. Based on the results of the analysis carried out at the facts and analysis stage, related to meeting the demand for clean water, the community is still experiencing difficulties because the source of clean water

has not been able to cover the entire hamlet (see Figure 4). However, using pure water sources from other villages, the fulfillment of clean water is still constrained by quality and quantity. In the dry season, the amount of water decreases due to drought; in the rainy season, the water quality becomes cloudy. The people of Janjang Wulung Village already have access to their telecommunications needs. However, there are still obstacles related to providers who can only cover some hamlets and unstable network conditions. The condition of human resources in Janjang Wulung Village is still not good due to the role of institutions that have not been maximized and the absence of counseling for community groups in Janjang Wulung Village. The lack of this role has resulted in the people of Janjang Wulung Village being unable to optimize their needs or resources. The community does not yet have sufficient knowledge to manage production and market commodity products.

The condition of the COVID-19 Pandemic is also one thing that affects the shape of Janjang Wulung Village. With this condition, the village economy can contract and lead to a recession which impacts rural communities due to the declining level of purchasing power. This can limit the communication and social level of the village community and reduce the productivity of various sectors in Janjang Wulung Village.

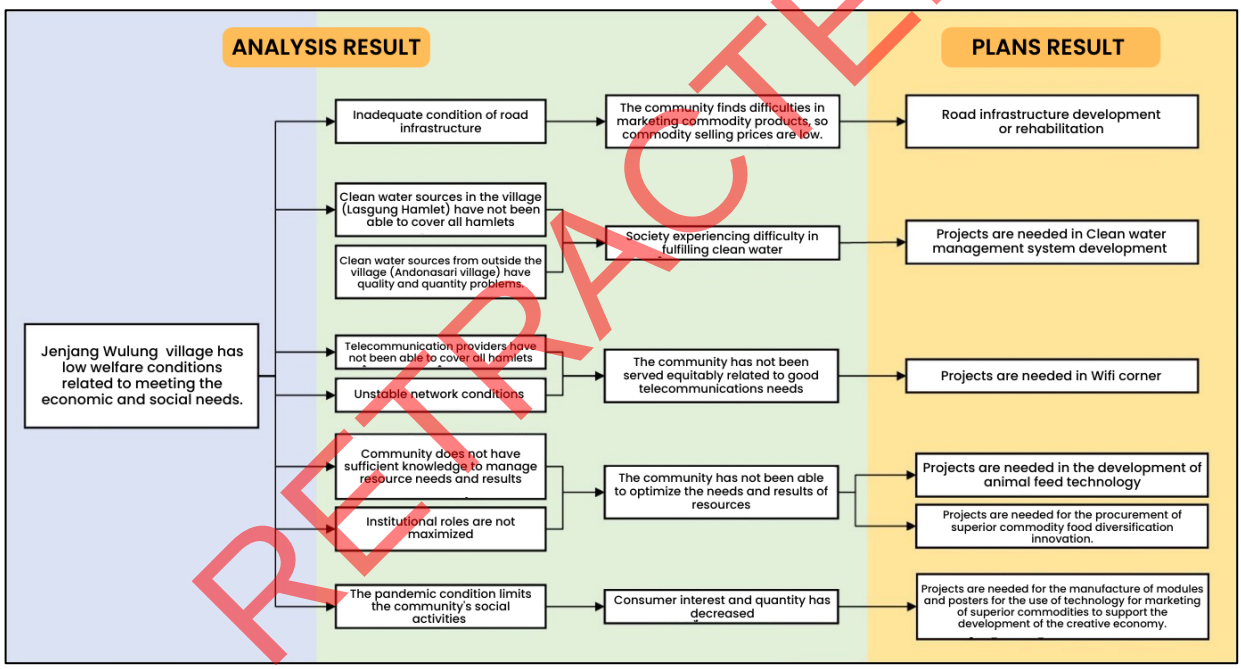

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Figure 4 Janjang Wulung Village Development Concept Flowchart

Before realizing the directives for the plan to develop Janjang Wulung Village, a Project Alternative Analysis is needed, which determines the priority of programs or projects in Janjang Wulung Village based on the results of the Focus Group Discussion. The steps taken in determining the priority of the program or project in question are as follows.

3.5. Determination of Criteria

Criteria are determined based on the interest and priorities of the parties involved. Thus, 13 criteria were set according to the Project Alternative Analysis (AAP) that had been determined. The thirteen criteria are maximum beneficiaries, increased income, increased use of human resources, availability of natural resources, sustainability, duplication, replicability, inter-village project linkages, tool-to-purpose relationship, ecological considerations, contribution to

district/municipality strategic programs, the priority order of development principles with the region, and relation to the previous year's program.

1. Determination of Weighting Value

   This value-weighting stage is carried out by assigning a value to each existing project alternative using predetermined criteria. The following is the weighted value of the Likert Scale to assess AAP.

   1 = Very Low
   2 = Low
   3 = Enough
   4 = Height
   5 = Very High

2. Determination of Project Alternatives (AAP)

Table 4 Project Rating Matrix

No. Project	Project	Score	Rank
1	Road Construction and Rehabilitation Project	427.5	I
5	Clean Water System Management System Development Project	422.4	II
8	Wifi Corner Procurement Project	412.5	III
4	Animal Feed Technology Development Project	400	IV
7	Module and Poster Development Project Using Technology for Leading Commodity Marketing to Support Creative Economy Development	392.5	V
6	Procurement of Leading Commodity Food Diversification Innovation	385	VI
2	Health Facilities Rehabilitation and Performance Improvement Project	360	VII
3	Education Facility Improvement and Performance Improvement Project	337.5	VIII
9	Institutional Performance Improvement Project	260	IX

Based on the project rating and identification of the physical and non-physical potential of Janjang Wulung Village, plans or directions for developing the village and community are determined. The following is a table of orders for the plan to develop Janjang Wulung Village.

Table 5 Directions for the Janjang Wulung Village Development Concept Plan

Plan Form	Plan Direction	Alternative Plan	Plan Purpose
Spatial Structure Plan	Accessibility Quality Improvement	Road Construction and Rehabilitation	Village Physical Fulfillment
	Clean Water Network Development	**Development of Clean Water System Management:** Addition of Piping Network	Village Physical Fulfillment
Space Pattern Plan	Facility Construction and Rehabilitation	**Repair and Improvement of Health Facilities Services:** Construction of New Classroom	Village Social and Physical Fulfillment
		Procurement of wifi Corner	Village Social, Economic, and Physical Fulfillment
		Development of Clean Water System Management: Addition of Reservoir and Clean Water Pump	Village Physical Fulfillment
		Repair and Improvement of Health Facilities Services: Polindes Building Rehabilitation	Village Social and Physical Fulfillment

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Plan Form	Plan Direction	Alternative Plan	Plan Purpose
HR and Natural Resources Fulfillment Plan	Quality Development of Livestock Activities	Animal Feed Technology Development	Economic Fulfillment
	Improved Quality of Leading Commodities	Procurement of Leading Commodity Food Diversification Innovation	Economic Fulfillment
	Training on Using Technology for Leading Commodity Marketing	Making Modules and Posters on the Use of Technology for Marketing Leading Commodities to Support Creative Economy Development	Social and Economic Fulfillment
	Improving the Quality of Health Services	**Repair and Improvement of Health Facilities Services:** Improving of Polindes Services	Social Fulfillment
	Improving the Quality of Education Services	**Improvement and Improvement of Educational Facilities Services:** Improving Education Facilities	
	KUD Performance Improvement	Institutional Performance Improvement	
	LPM Performance Improvement		

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The spatial structure contains plans for service centers, service sub-centers, and linkage systems. After being identified, it gave rise to Krajan Hamlet as a service center, Kopek Hamlet as a service sub-center, with directions for improving the quality of accessibility and clean water networks See Figure 5 and Figure 6).

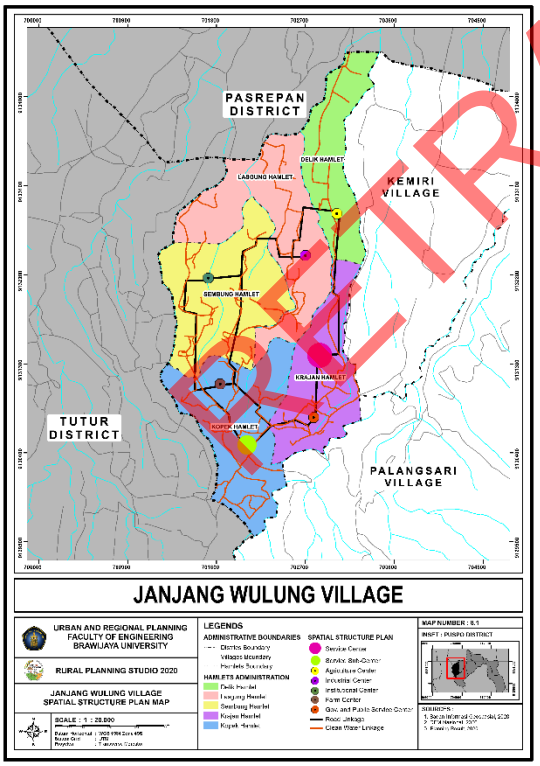

Figure 5 Janjang Wulung Spatial Structure Plan

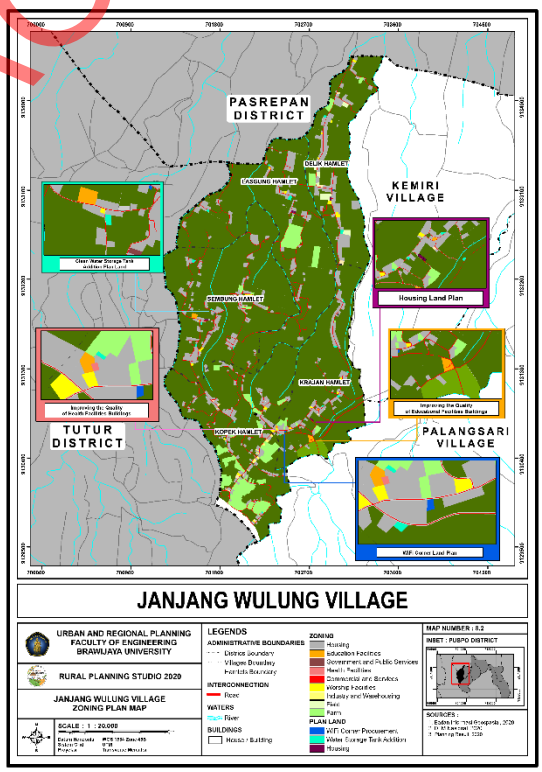

Figure 6 Janjang Wulung Spatial Pattern Plan

In addition, the spatial pattern plan itself discusses the plan to add land, especially for clean water facilities, educational facilities, health facilities, wifi corner facilities, and residential land.

Finally, the plan for fulfilling human resources and natural resources itself contains the direction of programs for the development of natural resources through the improvement and utilization of

human resources, which includes a non-physical plan for Janjang Wulung Village, which can be seen in Table 5.

So, from the plan, it is redefined to the needs based on the village and its community. It is divided into the physical resilience of the village and the non-physical resilience of the village community. The following is the division of projects based on the fulfillment of resilience.

Village Resilience: The fulfillment of village resilience is physical. This is explained by the conditions of Janjang Wulung Village, such as the road network, clean water, and telecommunications. So, the projects below were made to meet the village's resilience from its physical condition.

Road Rehabilitation Project: This project targets the rehabilitation of macadam roads and damaged roads into asphalt or paving roads to improve the hampered distribution process.

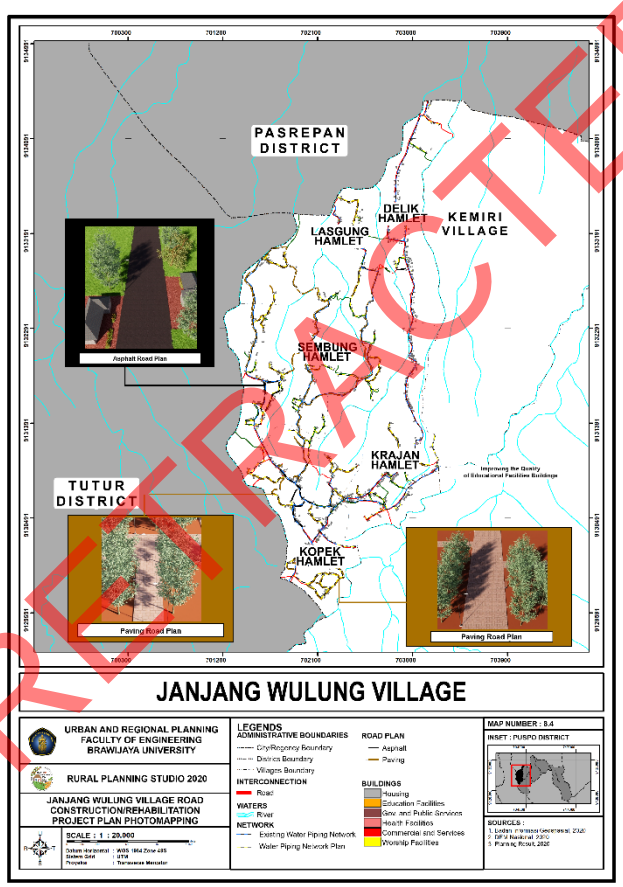

Figure 7 Photo Mapping of the Janjang Wulung Village Road Rehabilitation Project Plan

Clean Water System: This project aims to add clean water reservoirs, pipelines, and pumping systems to facilitate the distribution of clean water in Janjang Wulung Village (see Figure 8).

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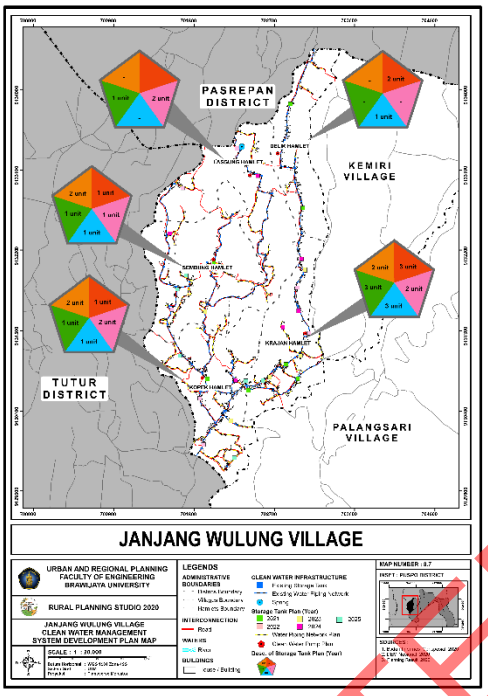

Figure 8 Janjang Wulung Clean Water System Plan

Wifi Corner Procurement Project: This project aims to fulfill network coverage for all hamlets so that the community can take advantage of the network related to online commodity marketing (see Figure 9).

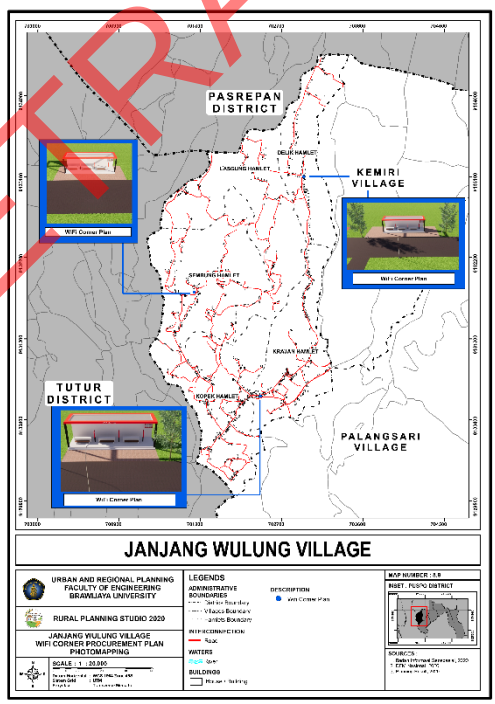

Figure 9 Photo Mapping the Plan to Procure WI-FI Corner in Janjang Wulung Village

Community Resilience: The plan's direction on community resilience discusses the non-physical plan of Janjang Wulung Village. This plan aims to meet the community's non-physical needs to

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support the creative economy's development. There are three projects of community resilience as follows.

Food Diversification Innovation Project: This project aims to fulfil the food security of the people of Janjang Wulung Village. In addition, this project is not only for food security but also one of the developments of the creative economy, namely the culinary sub-sector. Hopefully, with this project, the community will be able to utilize and adequately cultivate the potential of existing natural resources and gain profits if they are marketed.

Project for Making Modules and Posters on Using Technology to Support Creative Economy Development: This project was implemented to support projects directed at Janjang Wulung Village. This project contains methods and information related to the use of technology, especially online marketing of commodities. So, this project hoped to support the insight of the people of Janjang Wulung Village to improve their economy.

Animal Feed Technology Development Project: This project is aimed at cattle farmers. With this project, it is hoped that farmers can collaborate to utilize agricultural waste in animal feed. So, it is expected that farmers will have no difficulty finding animal feed again.

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4. CONCLUSION

Based on the results of the analysis that has been carried out, a project is needed to develop the village's potential during and after the COVID-19 Pandemic to achieve the welfare of rural communities in terms of economic and social fulfillment. Projects that can be carried out are the construction or rehabilitation of road infrastructure, and this is related to the majority of the population's livelihoods being farmers and breeders so that it can facilitate the marketing of commodity products, little decrease in selling prices during the process of going to the market and can support the social-economic fulfillment of rural communities. The second project is the development of a clean water management system. This project aims to meet the need for clean water so that the village community can obtain a good supply of clean water. The third project is the development of animal feed technology. With the inpri project, the village community will understand or know about alternative animal feed procurement, which is related to the livestock products produced. With good animal feed procurement, it is hoped that products with reasonable selling prices will be obtained to help the local economy. The next project is the procurement of superior commodity food diversification innovation. With this project, innovation will be carried out on commodity products to increase buying interest and selling prices and help improve the people's economy. The next project is the procurement of Wi-Fi Corner, which aims to meet the telecommunications needs of rural communities so that they can cover the entire hamlet with good quality. This project can also be used to develop village potential during and after the COVID-19 Pandemic. The next project is training in the use of technology for the marketing of superior commodities, and this project aims to increase the community's ability and knowledge of technology so that they can use it in marketing superior commodities so that they can survive during and after the COVID-19 Pandemic. Marketing superior commodities from these various sectors can assist the community in meeting economic needs. With these projects, it is hoped that the people of Janjang Wulung Village can optimize the potential of villages from various sectors to meet social needs.

With the preparation of these recommendations, it is expected to be able to plan a project that can overcome problems from the agricultural, livestock, institutional, economic, facilities and infrastructure sectors by developing the potential of Janjang Wulung Village during and after the

COVID -19 pandemic to be able to achieve good village community welfare in meeting economic and social needs.

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